


Contribution to HiLiftPW-3

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030

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Summary of cases completed: Solver: Dragon - TM: Wilcox k-ω 88

Case	Alpha=8, Fully turb, grid study	Alpha=16, Fully turb, grid study	Other
1a (full gap)	yes	yes	Full polar on all grid levels
1b (full gap w adaption)	no	no	
1c (partial seal)	no	no	
1d (partial seal w adaption)	no	no	
Other			

Grids: B2 (Pointwise)

Case	Polar, Fully turb	Polar, specified transition	Polar, w transition prediction	Other
2a (no nacelle)	yes	yes	no	
2b (no nacelle w adaption)	no	no	no	
2c (with nacelle)	no	no	no	
2d (with nacelle w adaption)	no	no	no	
Other				

Grids: E (ANSA)

Case	2D Verification study	Other
3	yes	
Other		

Grids: Supplied

Summary of cases completed: Solver: Dragon – TM: Wilcox k-ω 88

Case	Alpha=8, Fully turb, grid study	Alpha=16, Fully turb, grid study	Other
1a (full gap)	yes	yes	Full polar on all grid levels
1b (full gap w adaption)	no	no	
1c (partial seal)	yes	yes	Full polar on all grid levels
1d (partial seal w adaption)	no	no	
Other			

Grids: In-house (Pointwise)

Case	Polar, Fully turb	Polar, specified transition	Polar, w transition prediction	Other
2a (no nacelle)	yes	yes	no	
2b (no nacelle w adaption)	no	no	no	
2c (with nacelle)	yes	yes	no	
2d (with nacelle w adaption)	no	no	no	
Other				

Grids: In-house (Pointwise)

Brief overview of grid systems

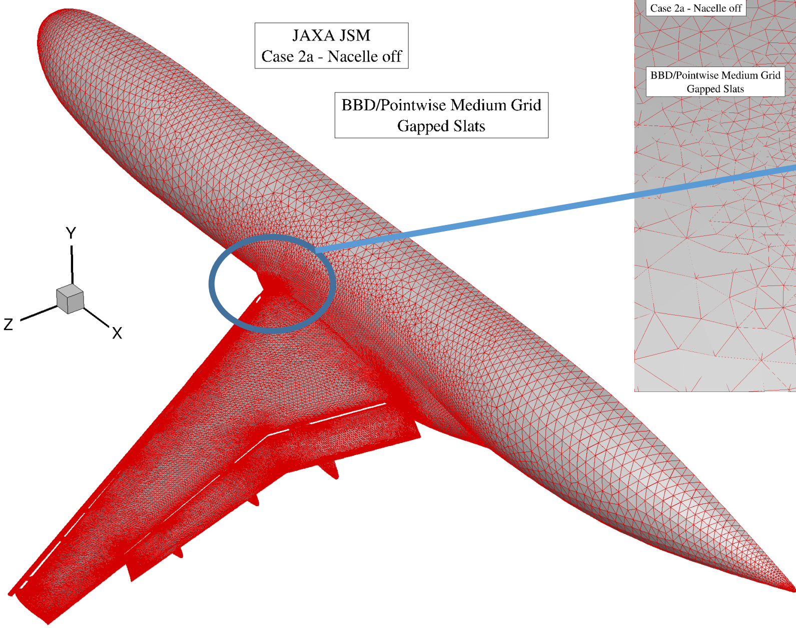
Grid System	Case(s)	If committee grid, report any problems/issues If user grid, reason for generating grid system
Committee – NASA CRM - Grids B2 (Pointwise)	1a	Had to regenerate CGNS files from Pointwise Could not preprocess extra-fine grid
User – NASA CRM – Mixed-element unstructured (Pointwise)	1a, 1c	Initially had issues reading the supplied grids Want to use this exercise as validation for our whole CFD package
Committee – JAXA JSM – Grids B (Solar)	2a	Solver diverged
Committee – JAXA JSM – Grids C2 (VGrid mixed)	2a	Convergence issues at high AoAs
Committee – JAXA JSM – Grids D	2a	Had to edit CGNS file for bc's and components (applies to all committee grids)
User – JAXA JSM - Mixed-element unstructured (Pointwise)	2a, 2c	Initially had issues reading the supplied grids Want to use this exercise as validation for our whole CFD package

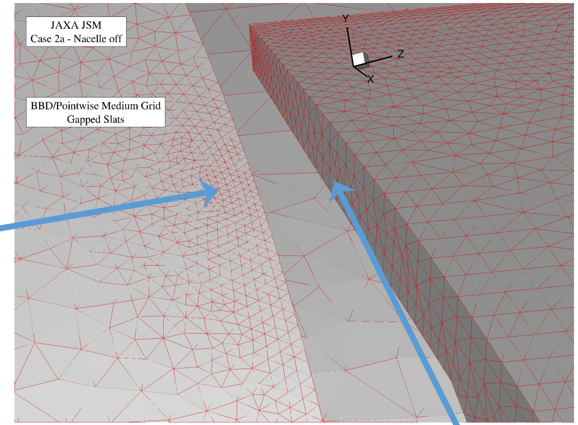
Dragon Flow Solver

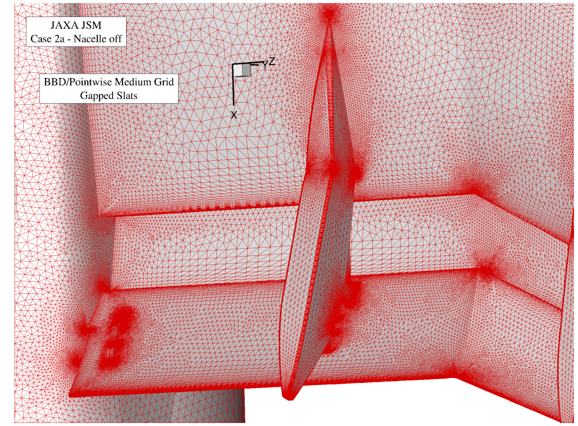
- Bombardier in-house 3D hybrid structured-unstructured RANS solver
  - Cell-centered, coupled solver
- Implicit time integration with LU-SGS approach
  - 1^{st}-order accurate in time for steady simulations
- 2^{nd}-order accurate Roe's upwind scheme for convective flux and central differencing scheme for viscous flux discretization
- Many turbulence models implemented
  - Wilcox k-ω 1988 model with curvature extension used
- Parallel large-scale simulation capability with non-blocking MPI
- Interfaced with CGNS data produced by main-stream commercial grid generators

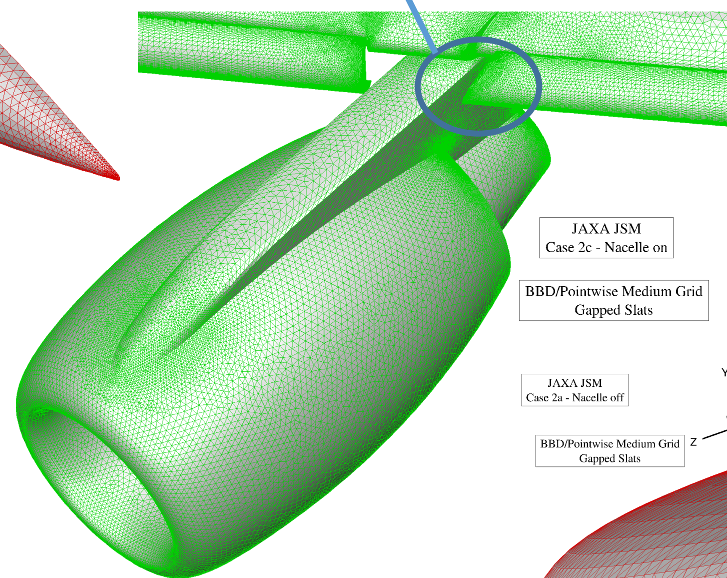
- Ref.: Yang, H. and Langlois, M. "Towards Accurate Simulation of Aircraft High-Lift Flows with One- and Two-Equations Turbulence Models", 62^{nd} CASI Aeronautics Conference, May 2015.

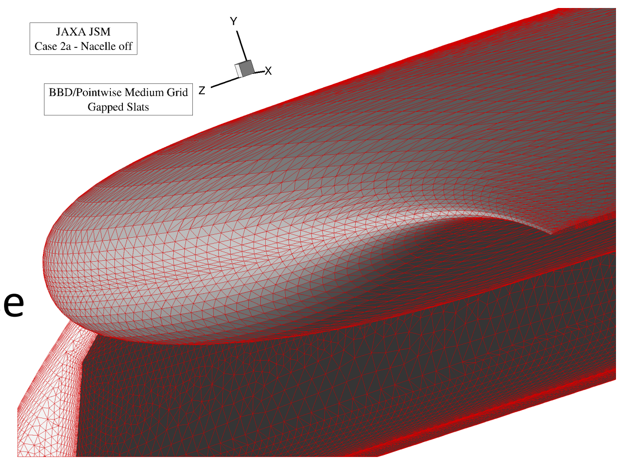
JAXA JSM results – Cases 2a/2c – Bombardier grids







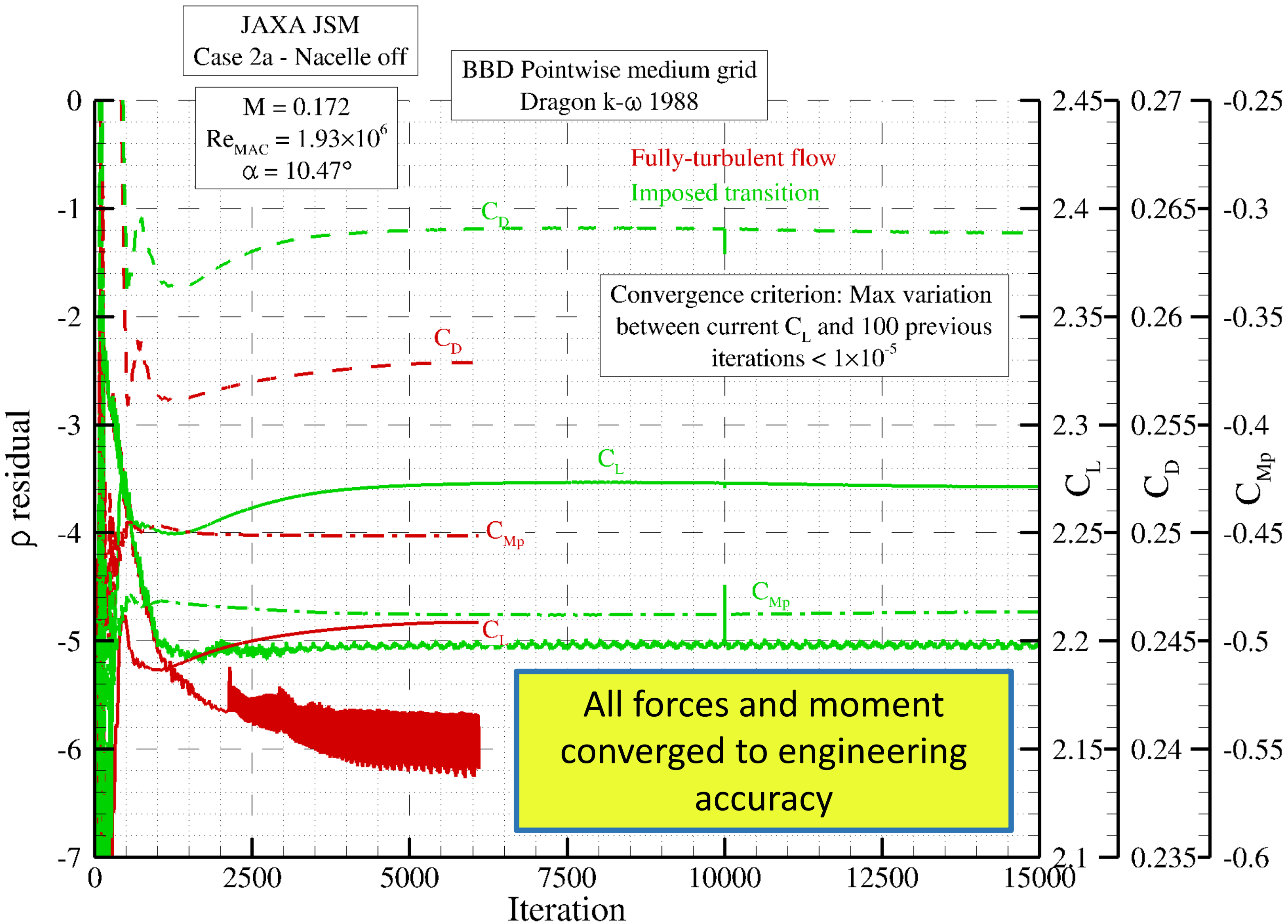




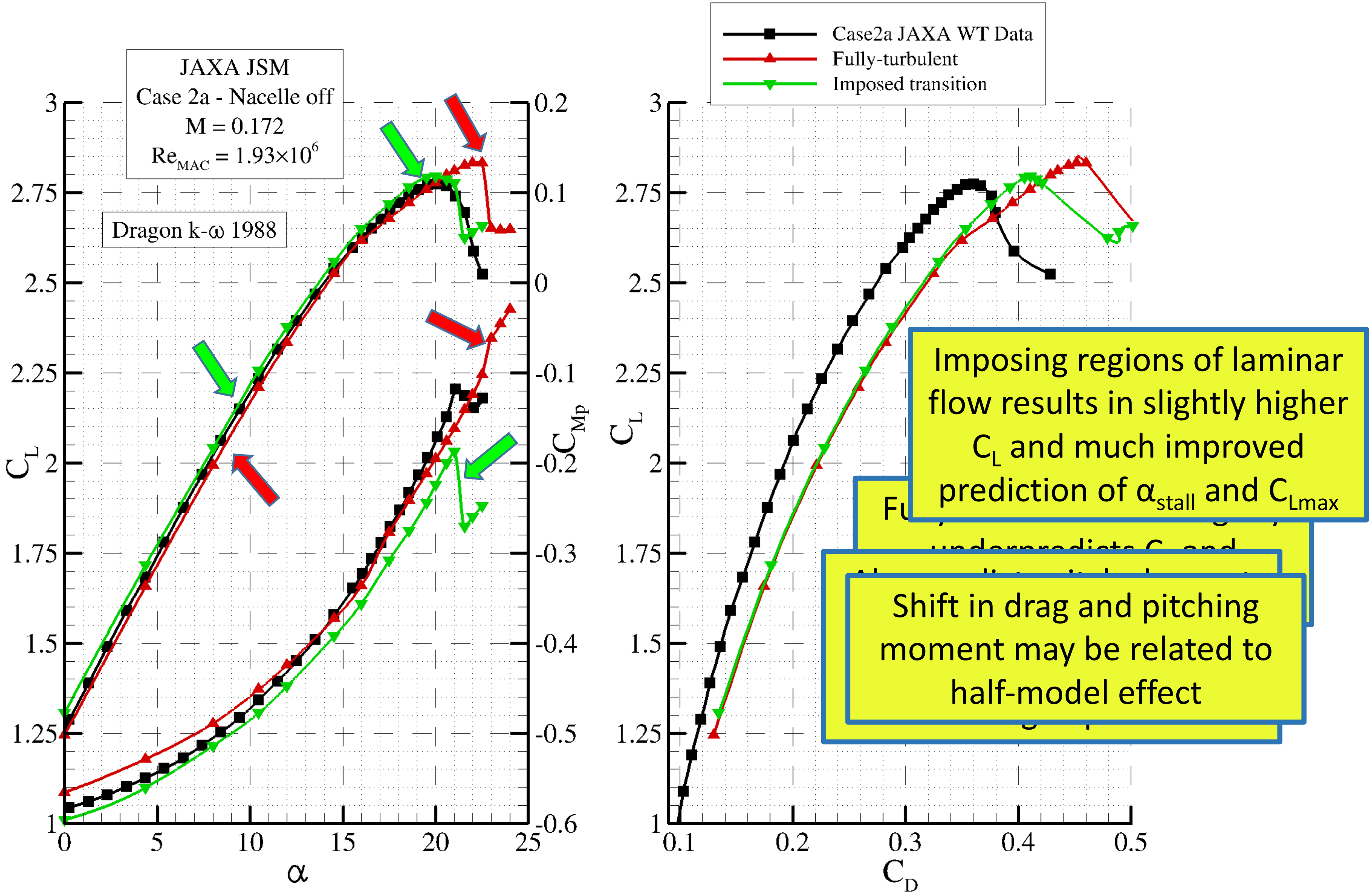
	Case 2a	Case 2c
Nodes	17 708 448	21 720 656
Cells	41 695 790	50 488 218
Fuselage	35 826	35 826
Wing	224 280	233 538
Slats	289 914	247 623
Flaps	253 048	253 048
Nacelle	-	174 472

Generated with Pointwise
Medium grid guidelines

JAXA JSM results – Transition influence: convergence history



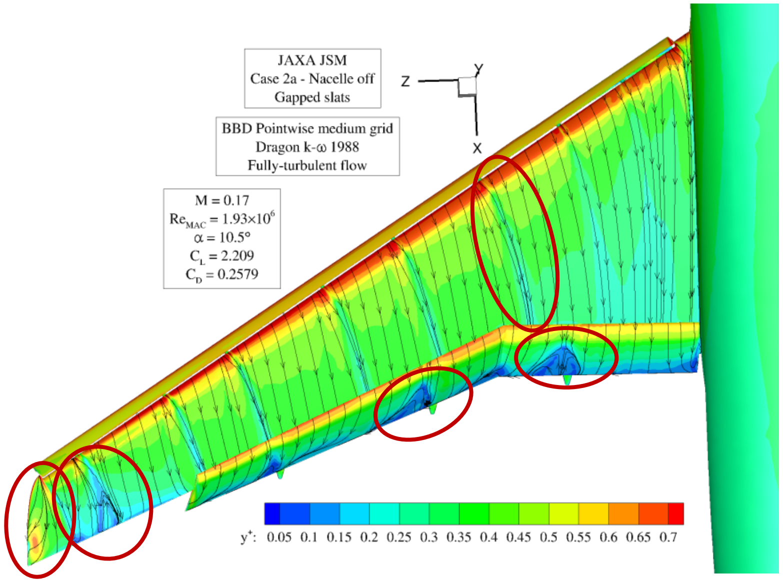
JAXA JSM results – Transition influence: forces & moments

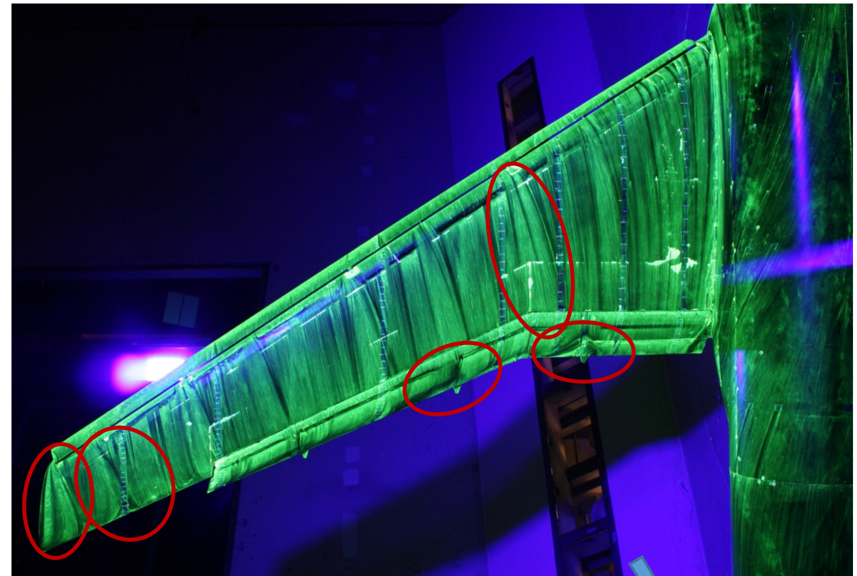


Imposing regions of laminar flow results in slightly higher C_L and much improved prediction of α_{stall} and C_{Lmax}

Shift in drag and pitching moment may be related to half-model effect

JAXA JSM results
Transition influence: surface flow pattern at mid α

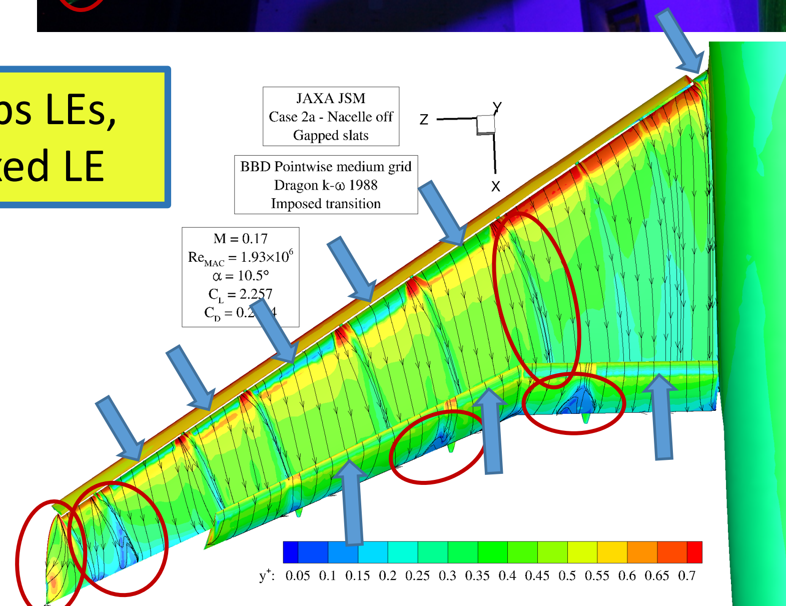




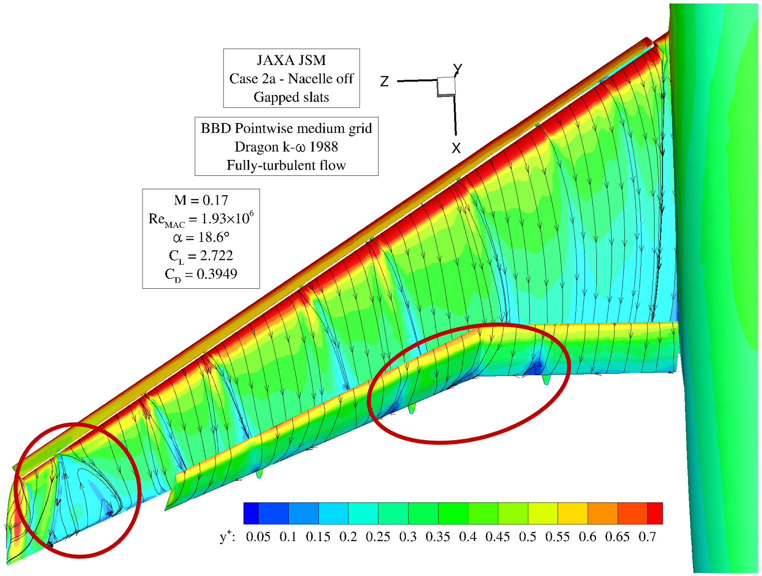
Laminar flow on flaps LEs, OB WUSS and IB fixed LE

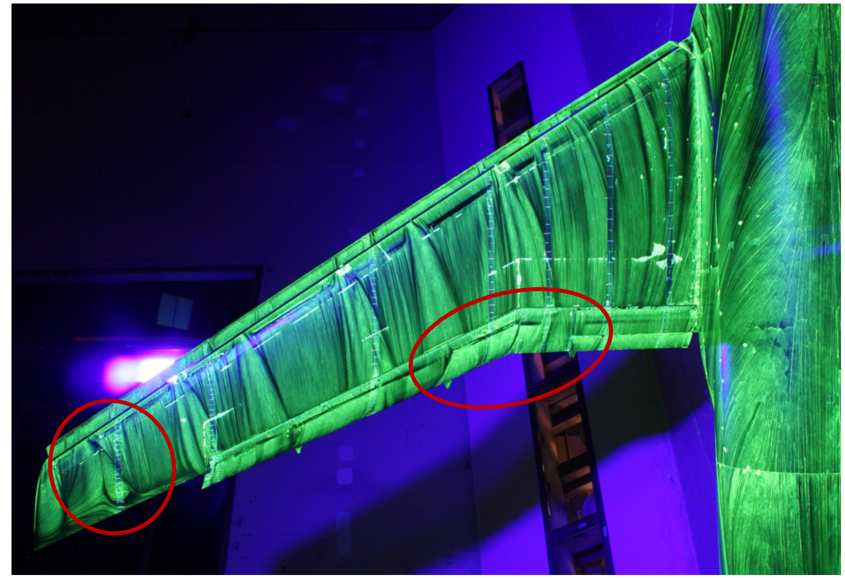
Flow pattern well predicted overall:

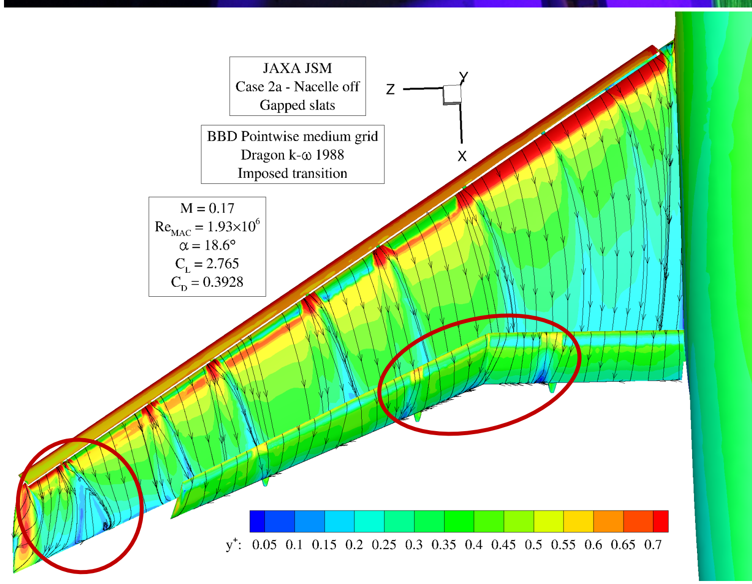
- Flow separation behind FTFs
- Flow separation behind most-OB slat track
- Wingtip separation
- Slat tracks vortices (lower y^+)



JAXA JSM results
Transition influence: surface flow pattern at high α

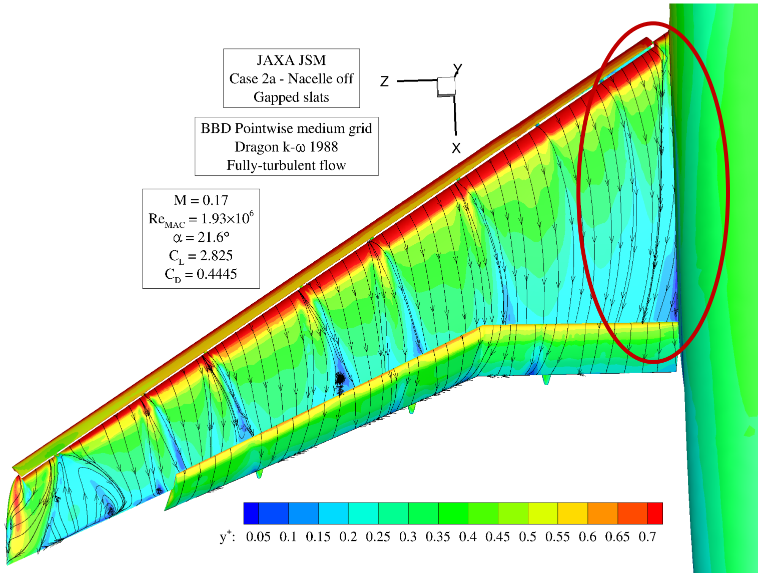


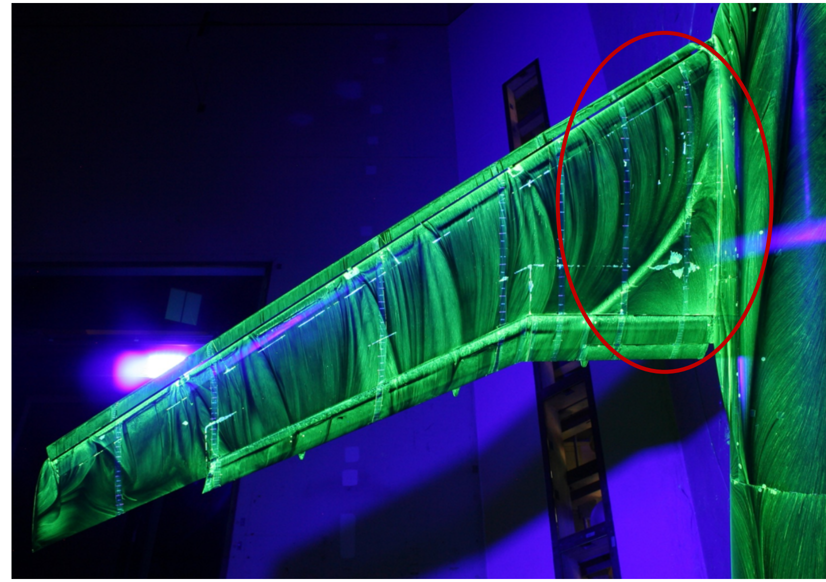


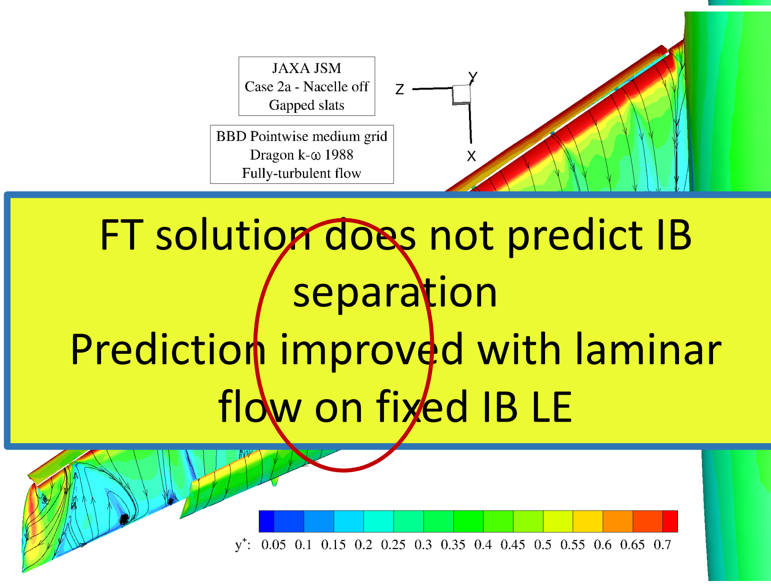


FT solution overpredicts extent of flow separation behind most-OB slat track and FTFs

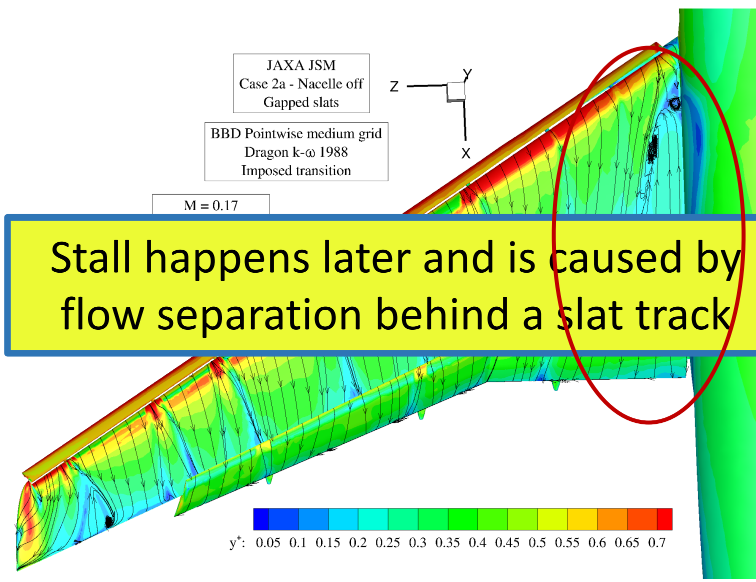
JAXA JSM results
Transition influence: surface flow pattern post-stall





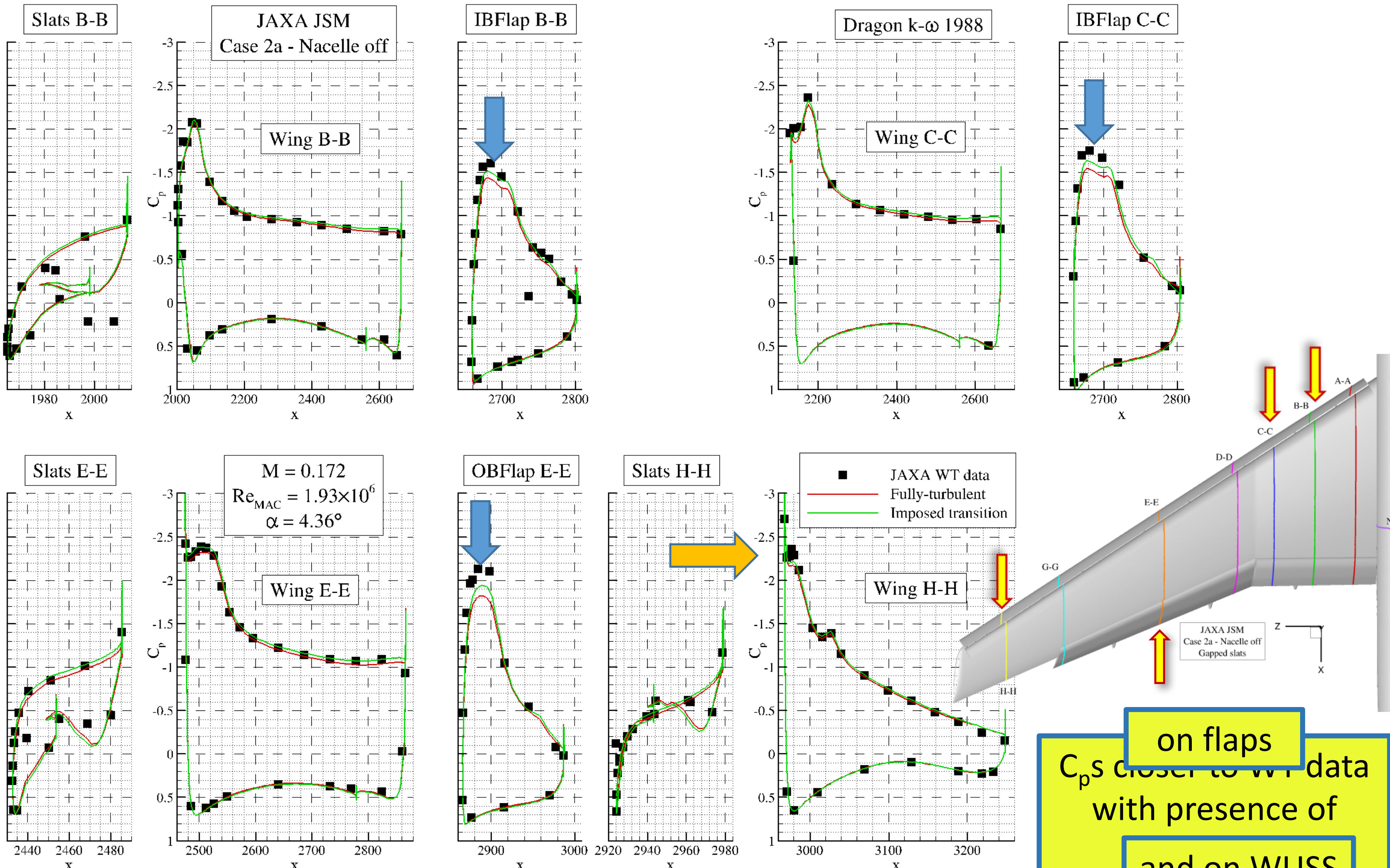


FT solution does not predict IB separation
Prediction improved with laminar flow on fixed IB LE



Stall happens later and is caused by flow separation behind a slat track

JAXA JSM results
Transition influence: pressure distributions at low α

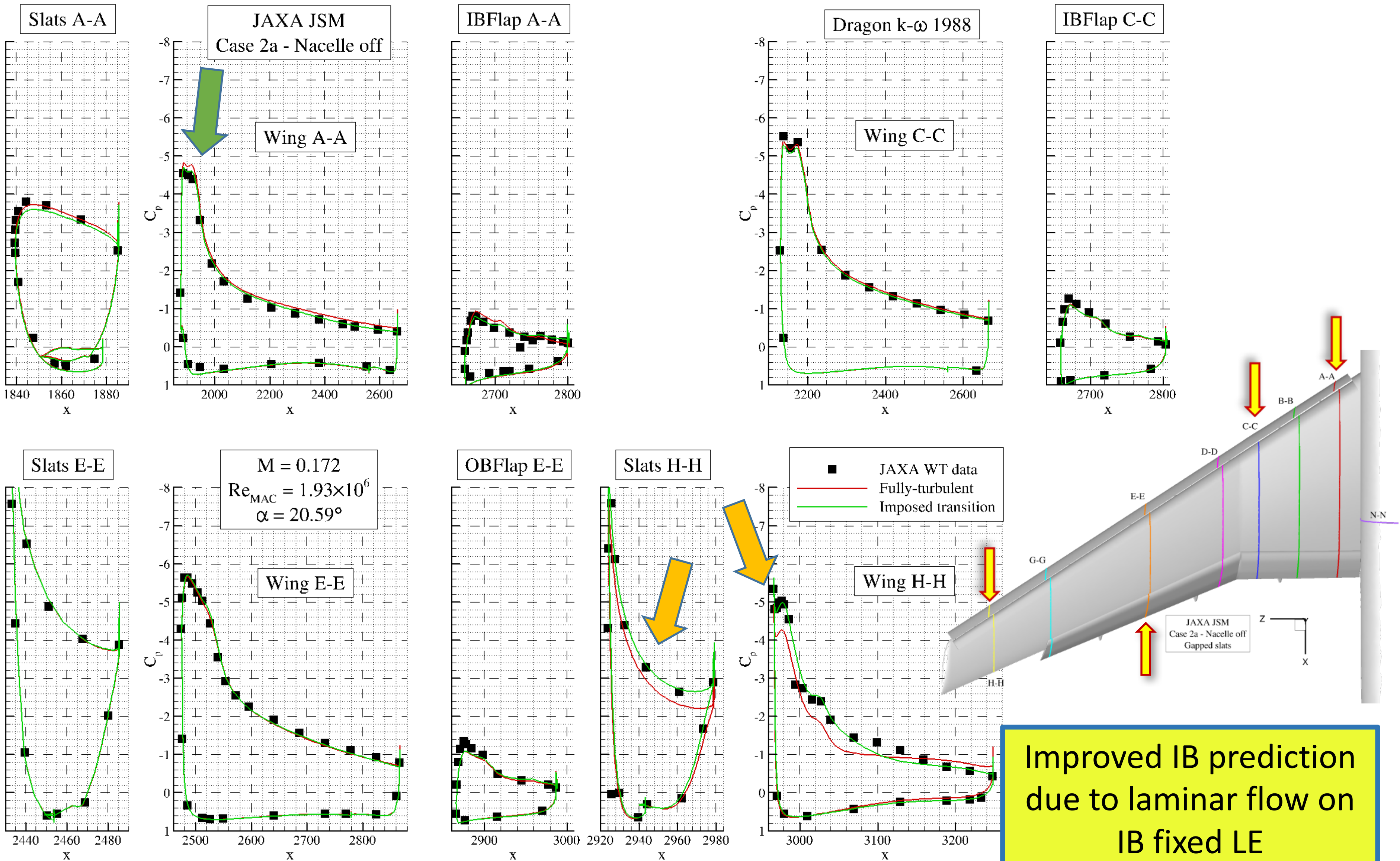


C_ps closer to WT data with presence of

on flaps

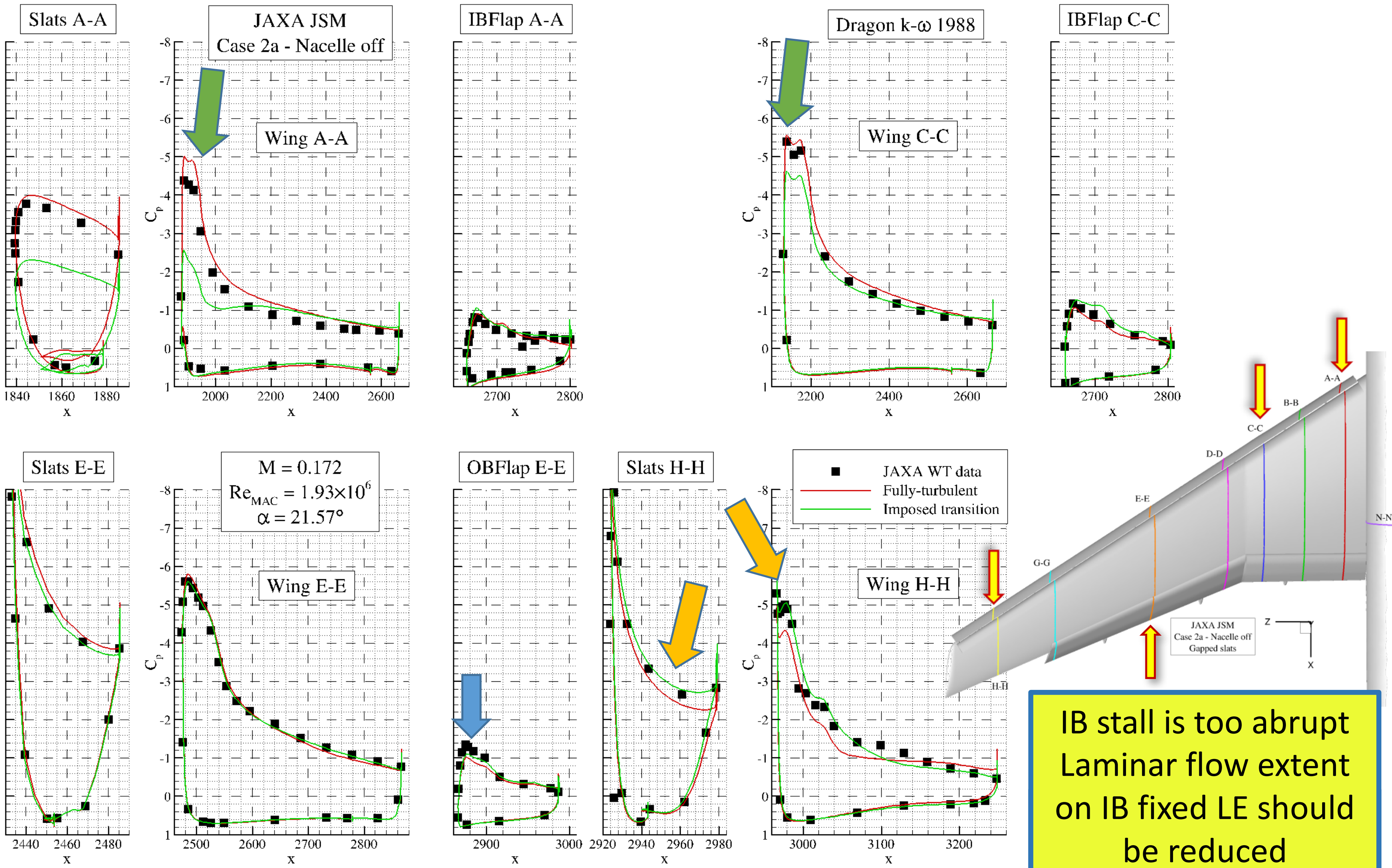
and on WUSS

JAXA JSM results
Transition influence: pressure distributions at stall



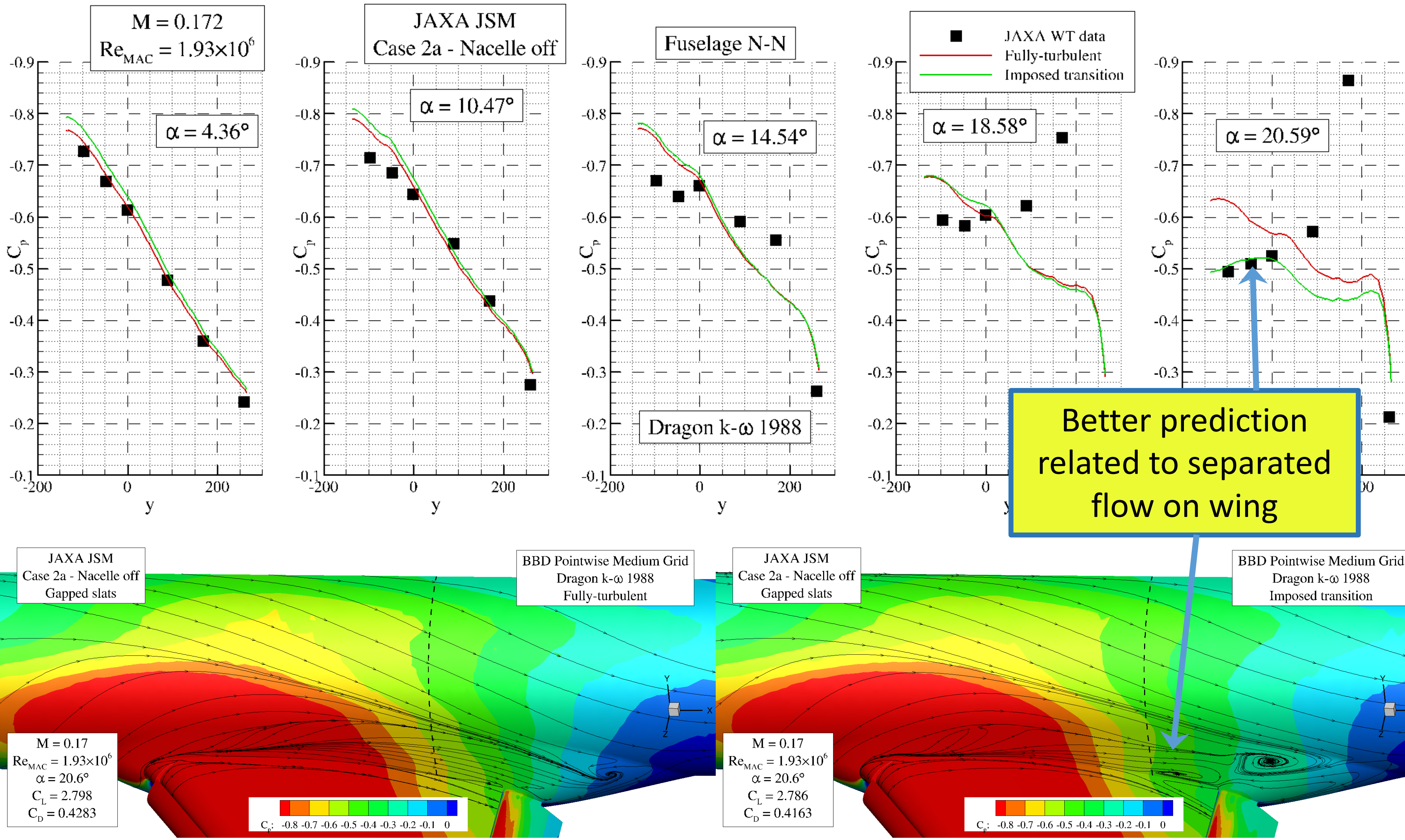
Improved IB prediction due to laminar flow on IB fixed LE

JAXA JSM results
Transition influence: pressure distributions post-stall

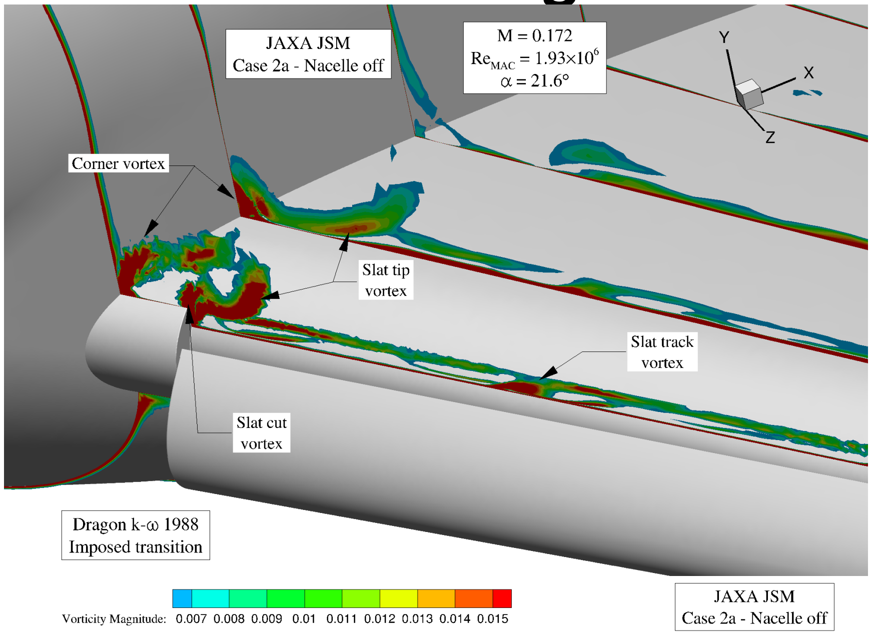


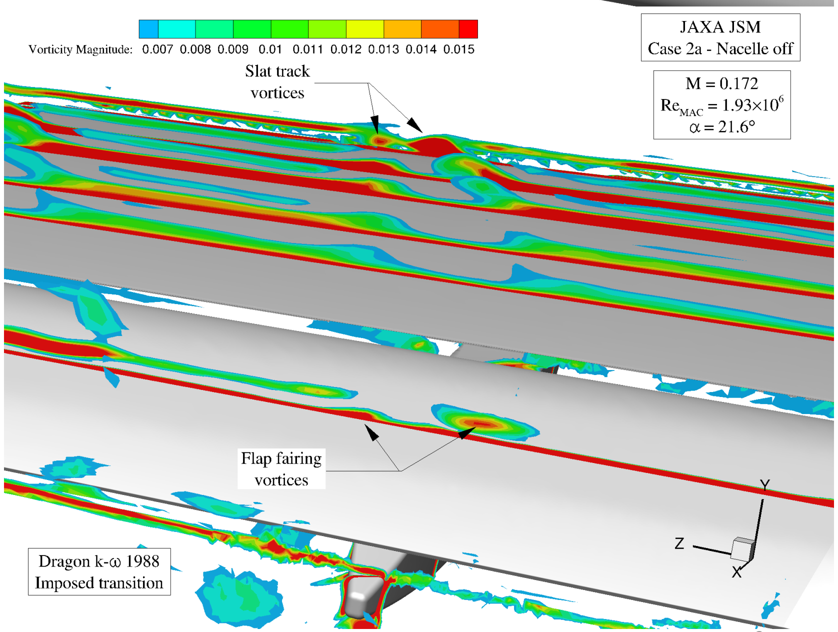
IB stall is too abrupt
Laminar flow extent on IB fixed LE should be reduced

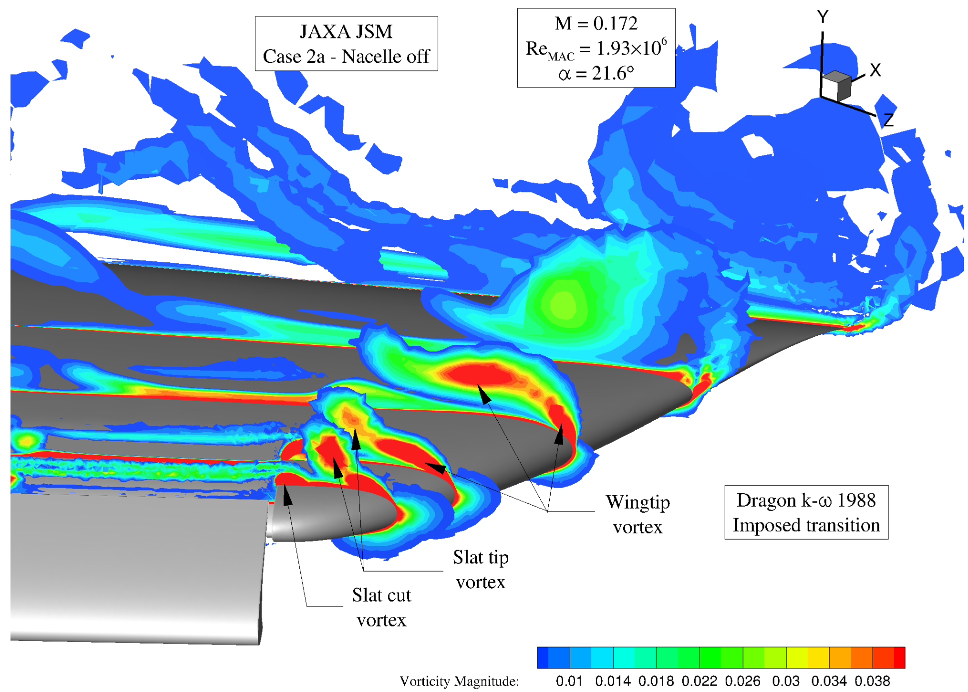
JAXA JSM results
Transition influence: pressure distributions



JAXA JSM results
Nacelle-off configuration: volume plots (post-stall)

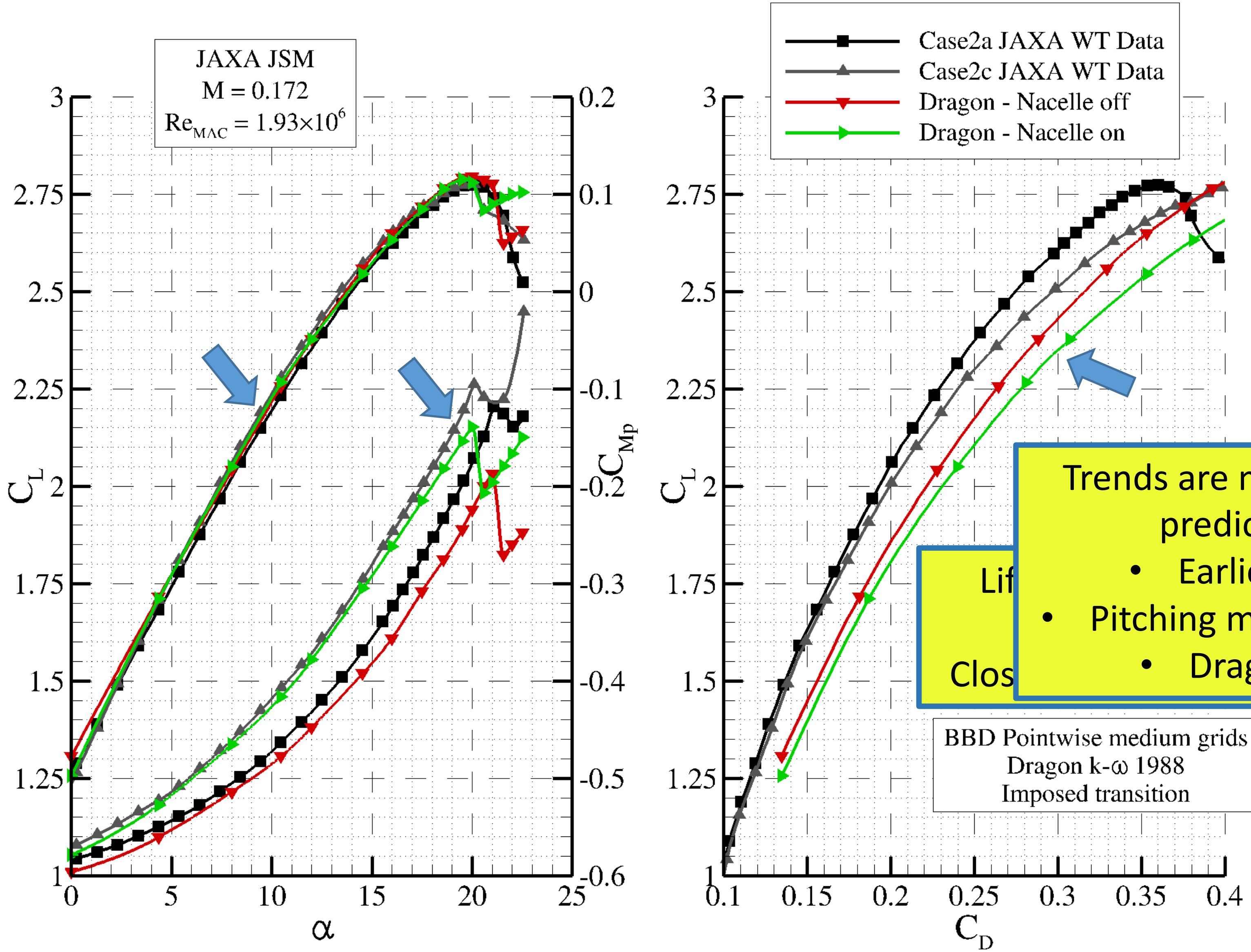






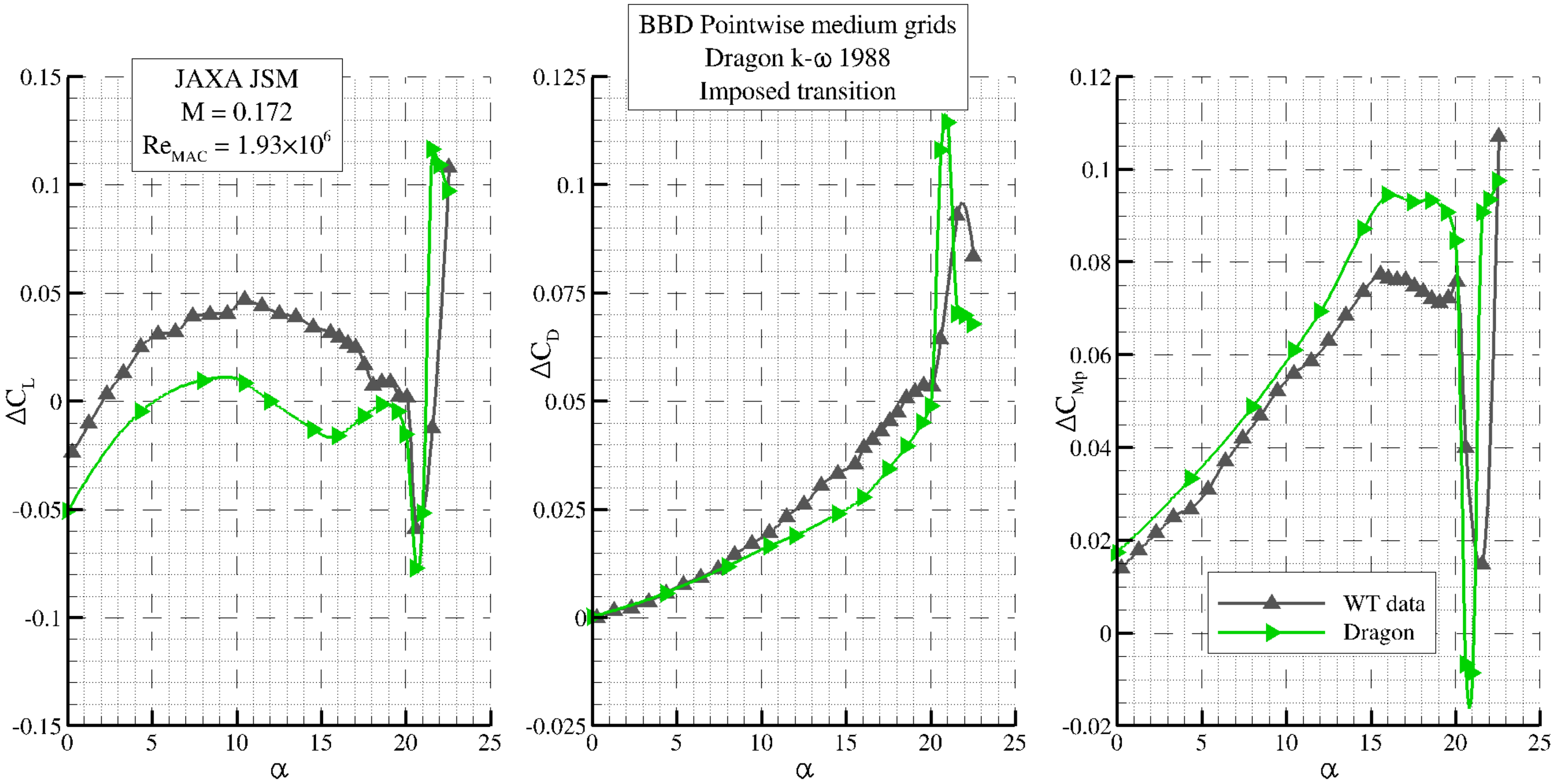
Main flow features are captured but likely dissipate too quickly
Volumic refinement/adaptation would be required

JAXA JSM results – Nacelle installation: forces & moments

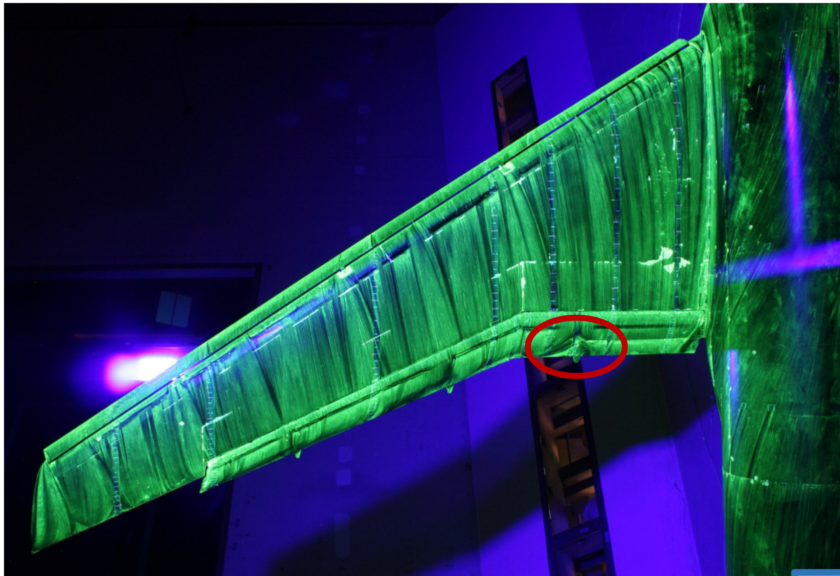


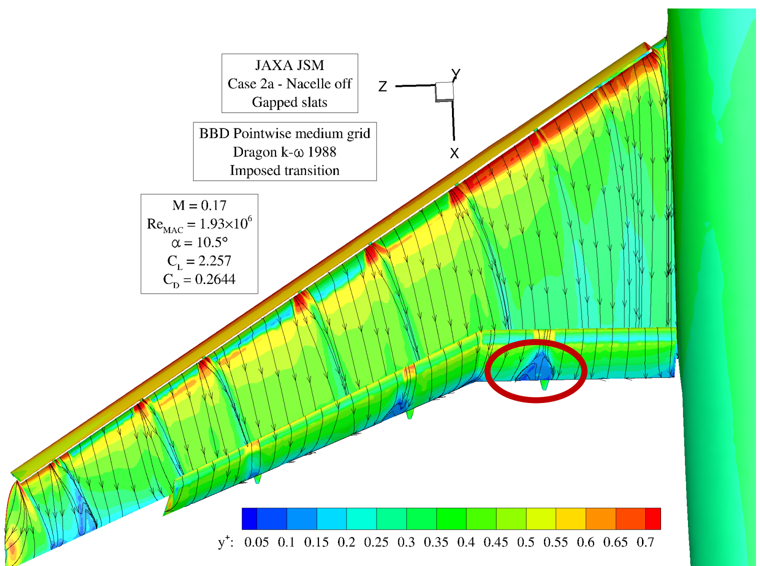
Trends are mostly well predicted:
- Earlier stall
- Pitching moment shift
- Drag shift

JAXA JSM results – Nacelle installation: forces & moments



JAXA JSM results
Nacelle installation: surface flow pattern (mid α)

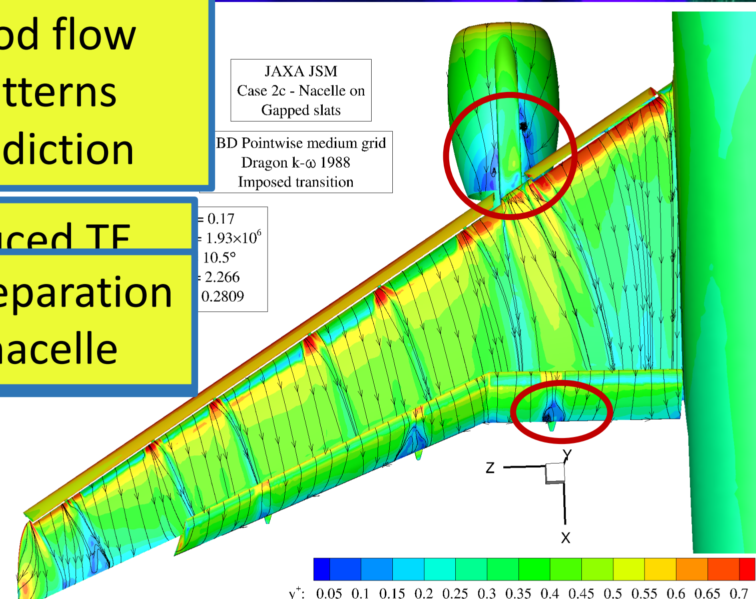




Good flow patterns prediction

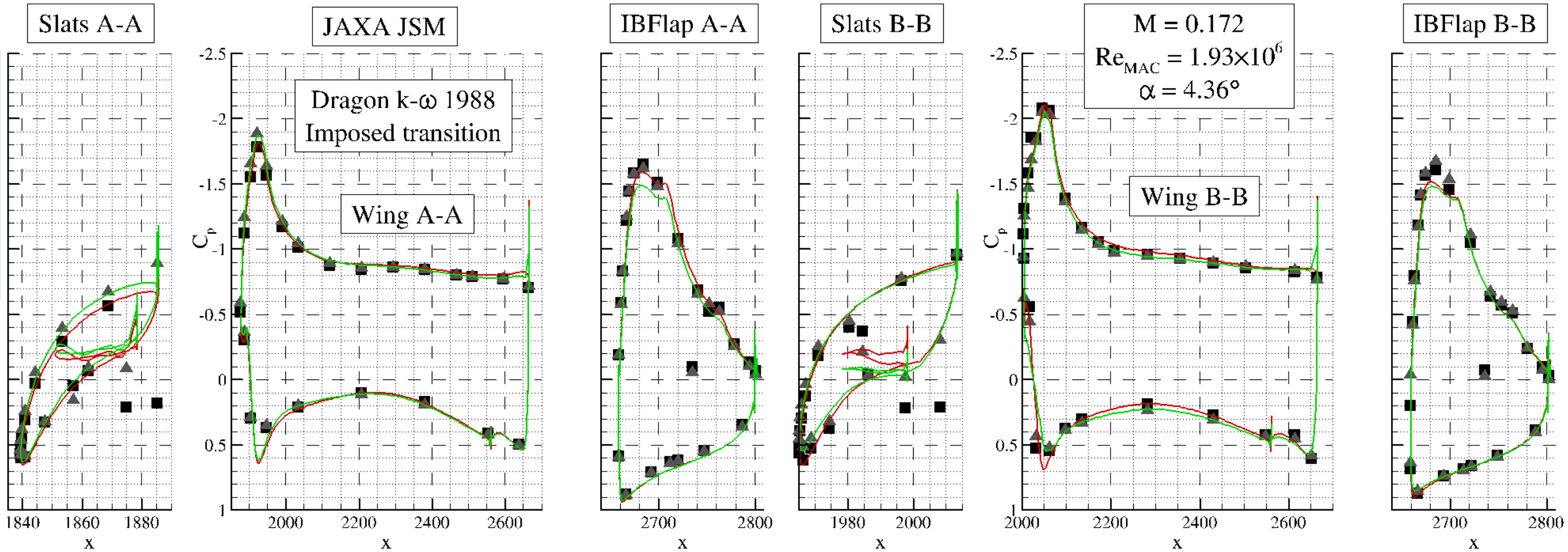
Reduced TE

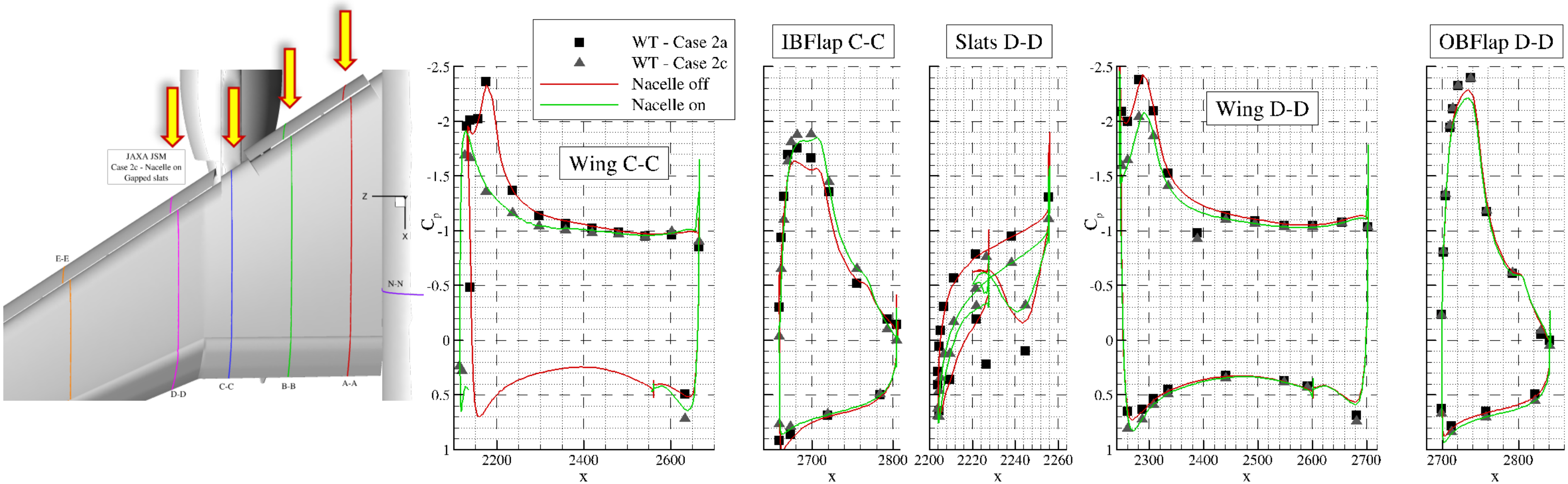
Flow separation on nacelle



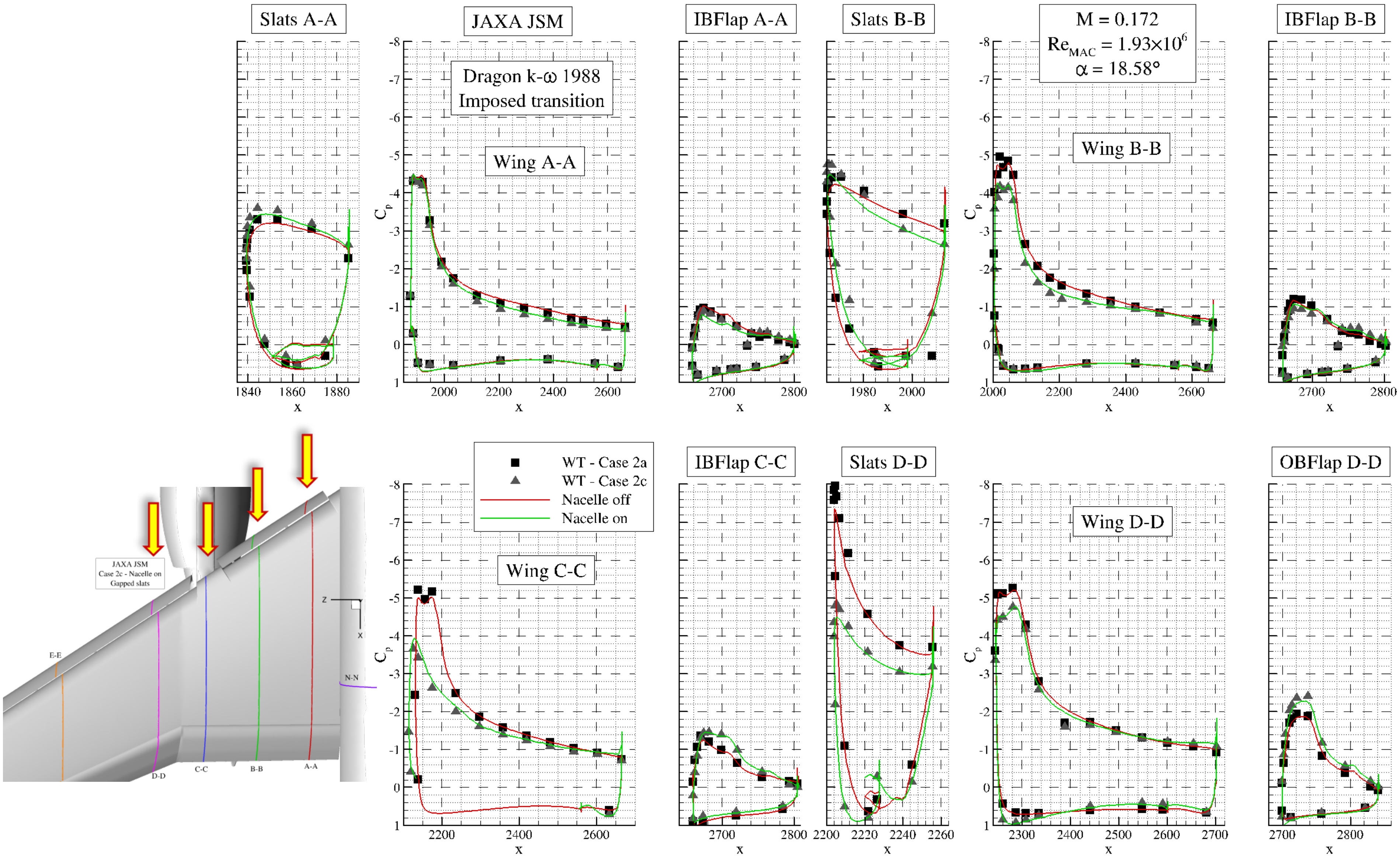
JAXA JSM results
Nacelle installation: pressure distributions at low α

Impact of nacelle on C_ps is well predicted





JAXA JSM results
Nacelle installation: pressure distributions at high α



NASA CRM grid systems

Bombardier Pointwise grids	Case 1a Coarse Grid	Case 1a Medium	Case 1a	Case 1c
Number of nodes	9 482 482			
Number of cells	23 379 645			

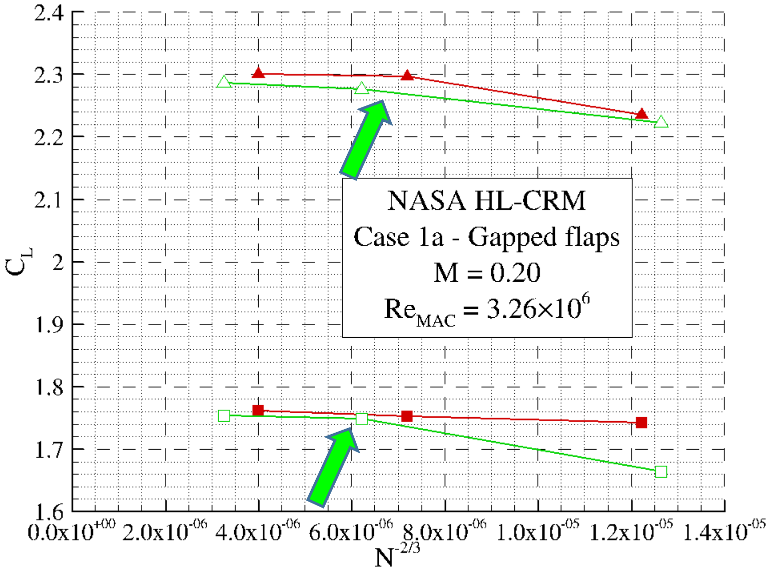
But B2 coarse grid has 3 times as many elements on the fuselage and less of a third on the flaps
The B2 fine grid has as many elements on the slats as on the wing

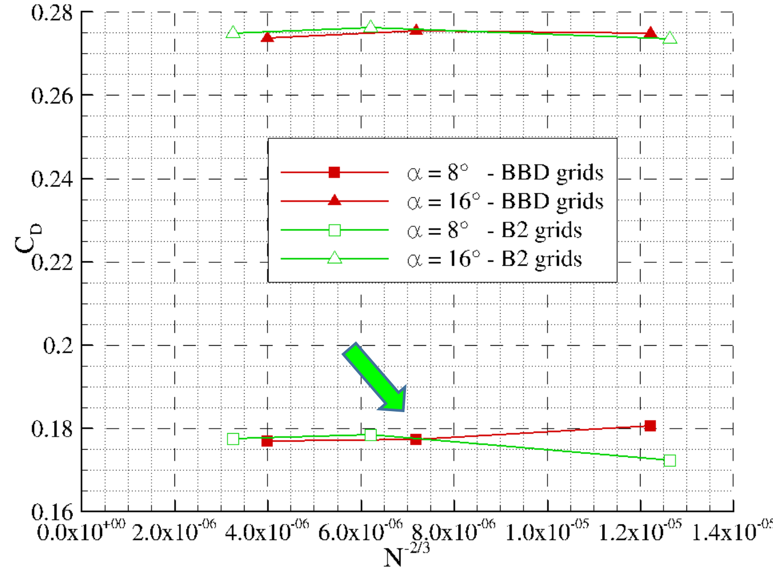
Committee B2 (Pointwise) grids	Case 1a Coarse Grid	Case 1a Medium Grid	Case 1a Fine Grid
Number of nodes	8 084 687	26 499 283	69 909 799
Number of cells	22 250 370	64 628 961	238 935 944

# of surface elements	BBD Coarse	B2 Coarse	BBD Medium	B2 Medium	BBD Fine	B2 Fine
Fuselage	23 401	73 441	38 738	183 098	63 140	407 763
Wing	205 767	219 14				
Slats	129 410	126 04				
IB flap	53 028	14 42				
OB flap	67 256	19 858	149 564	109 278	237 172	139 828

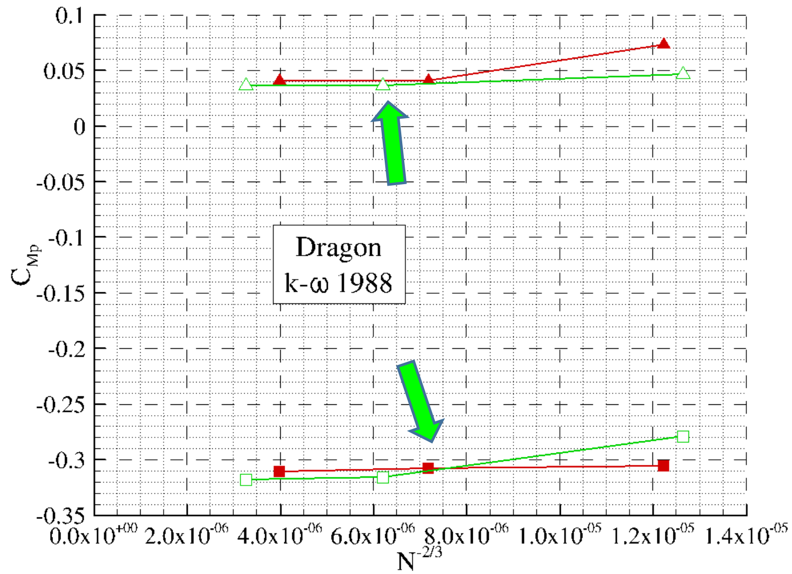
Bombardier and B2 coarse and medium grids have similar number of nodes and cells
B2 fine grid has almost twice as many cells as Bombardier fine grid

HL-CRM results – Grid convergence

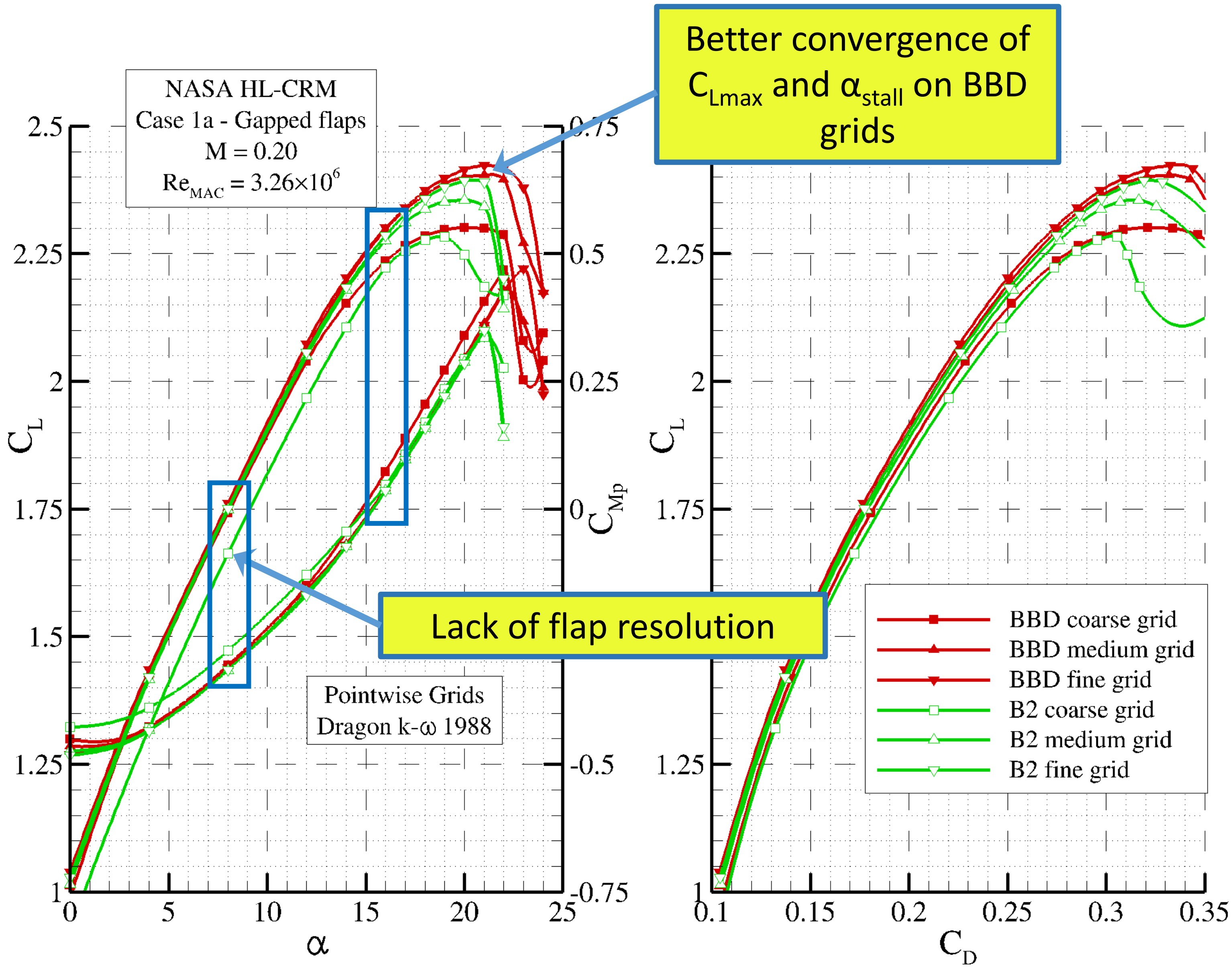




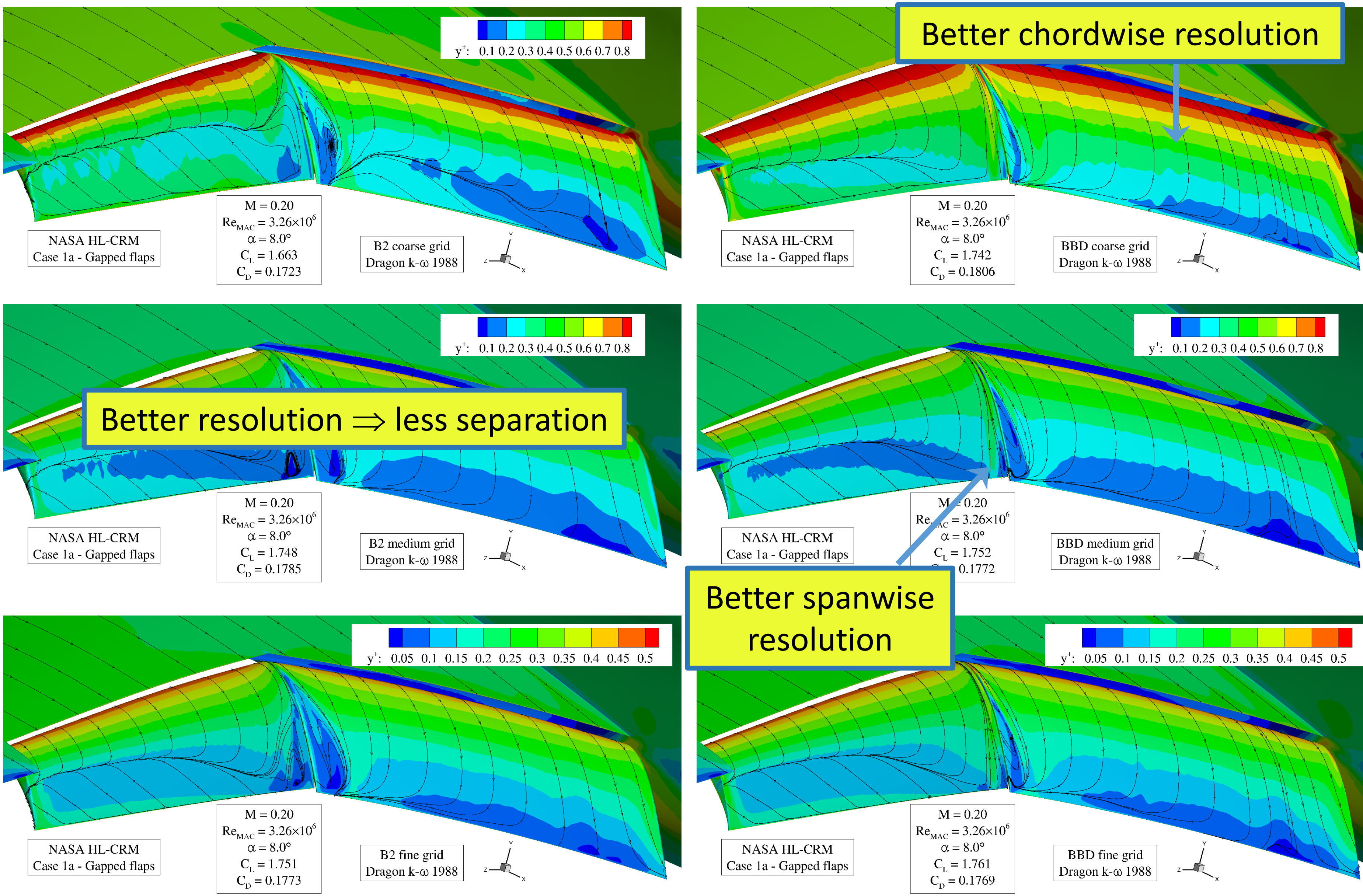
Grid convergence achieved on medium grids



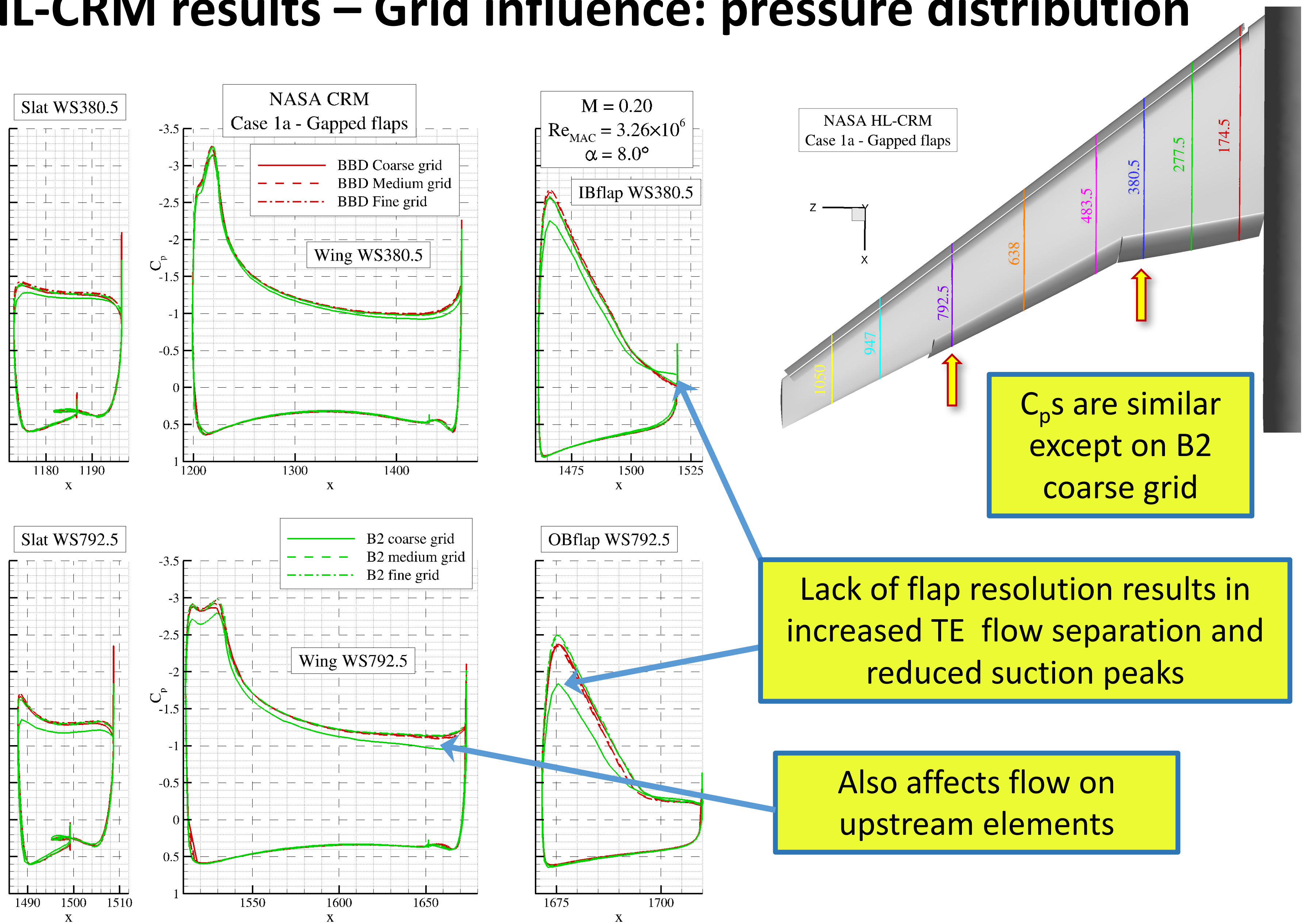
HL-CRM results – Grid influence: forces and moments



HL-CRM results – Grid influence: flaps flow pattern



HL-CRM results – Grid influence: pressure distribution

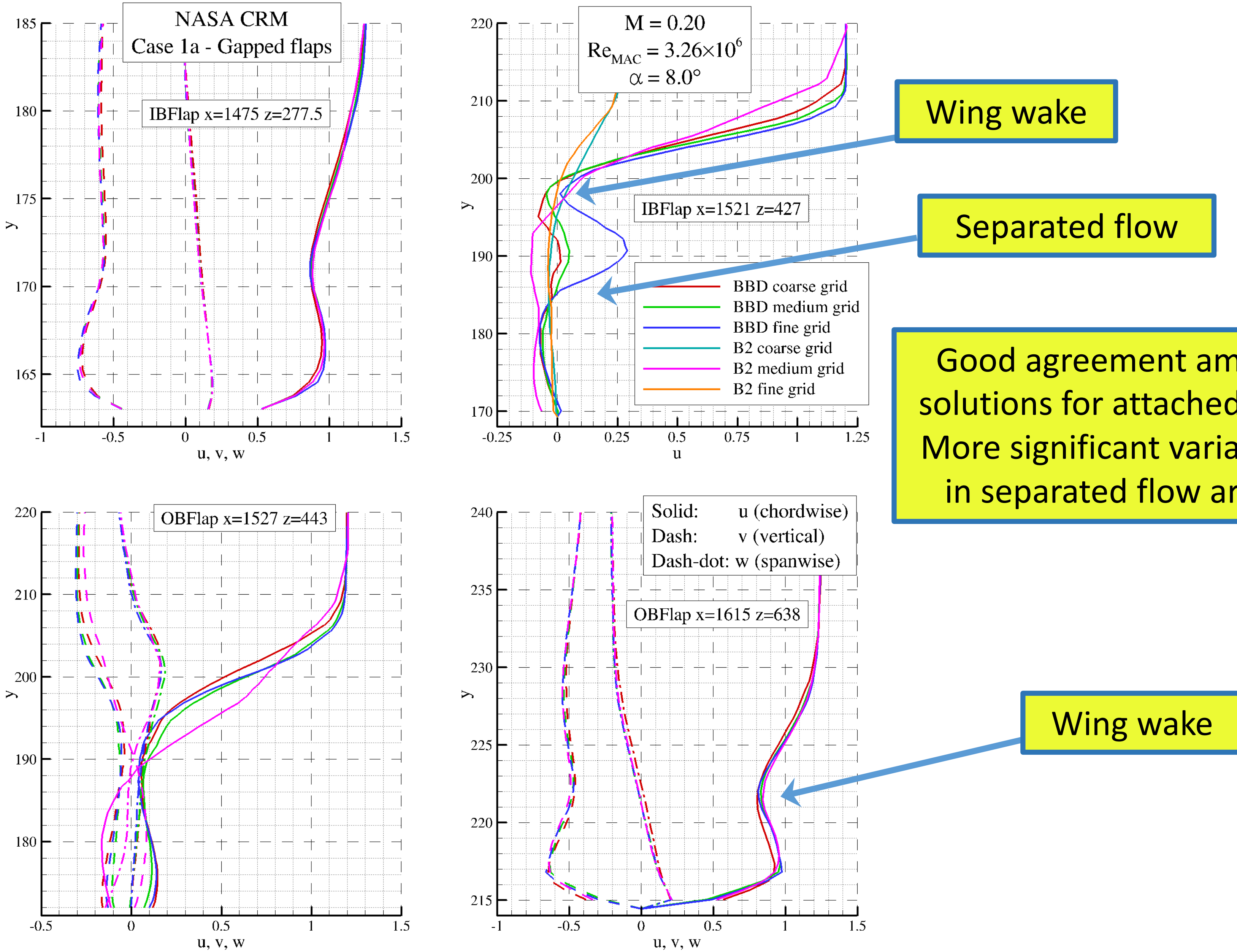


C_ps are similar except on B2 coarse grid

Lack of flap resolution results in increased TE flow separation and reduced suction peaks

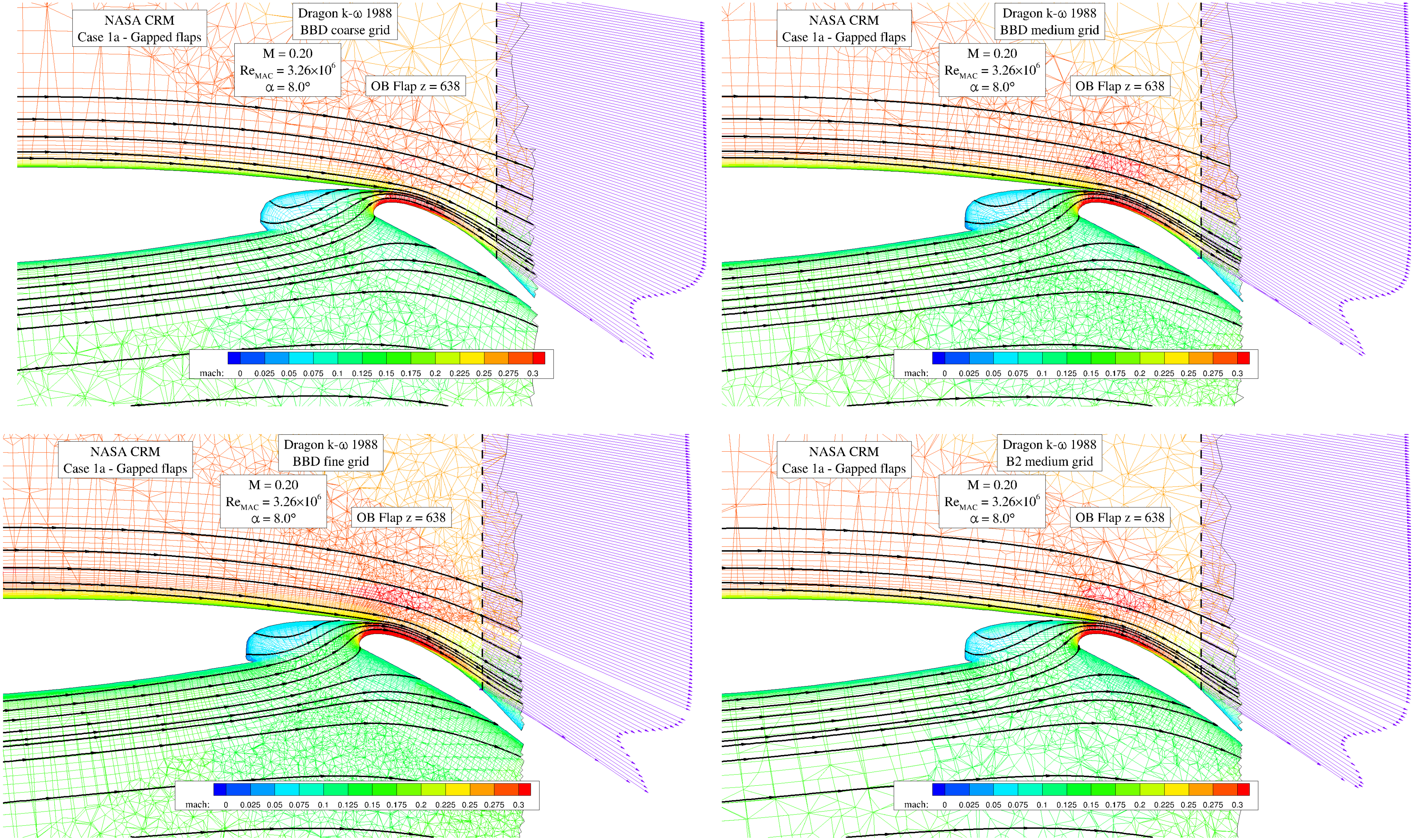
Also affects flow on upstream elements

HL-CRM results – Grid influence: velocity profiles

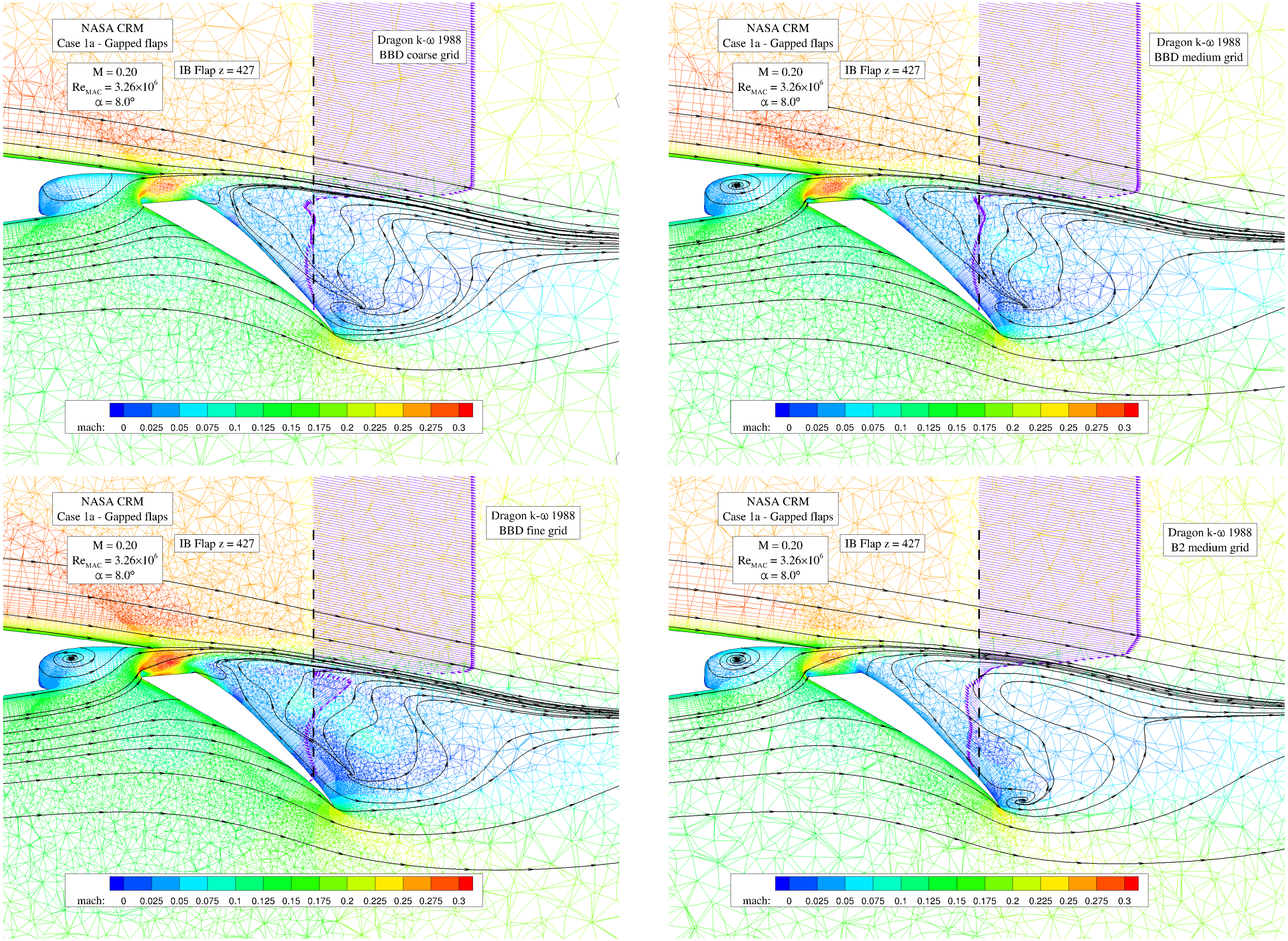


Good agreement among solutions for attached flow
More significant variations in separated flow areas

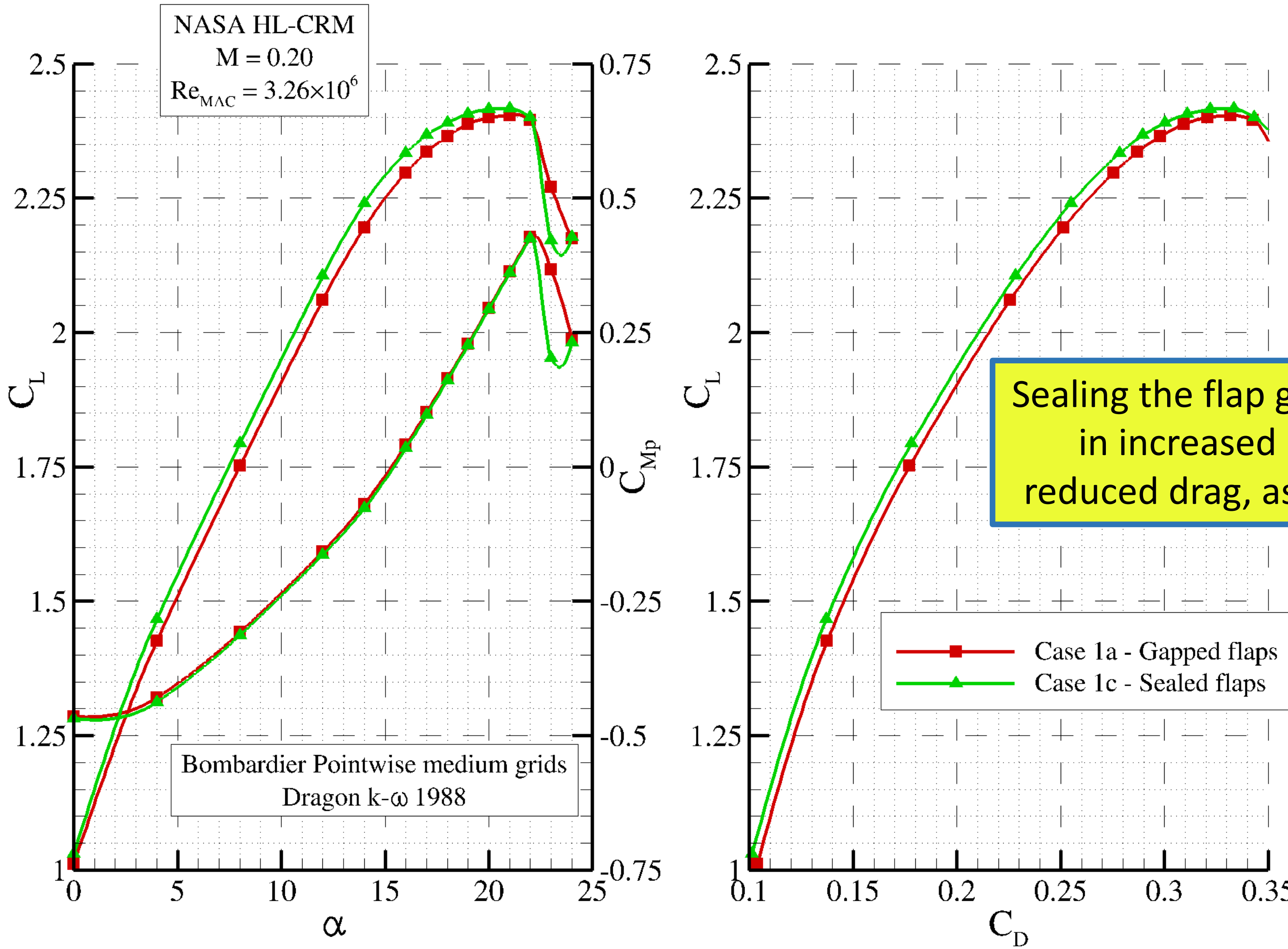
HL-CRM results – Grid influence: velocity profiles



HL-CRM results – Grid influence: velocity profiles

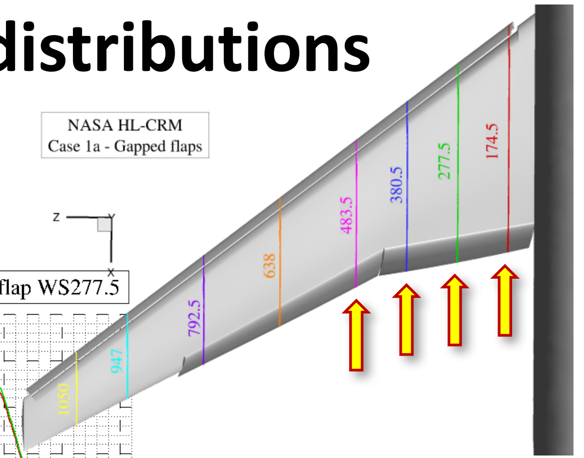


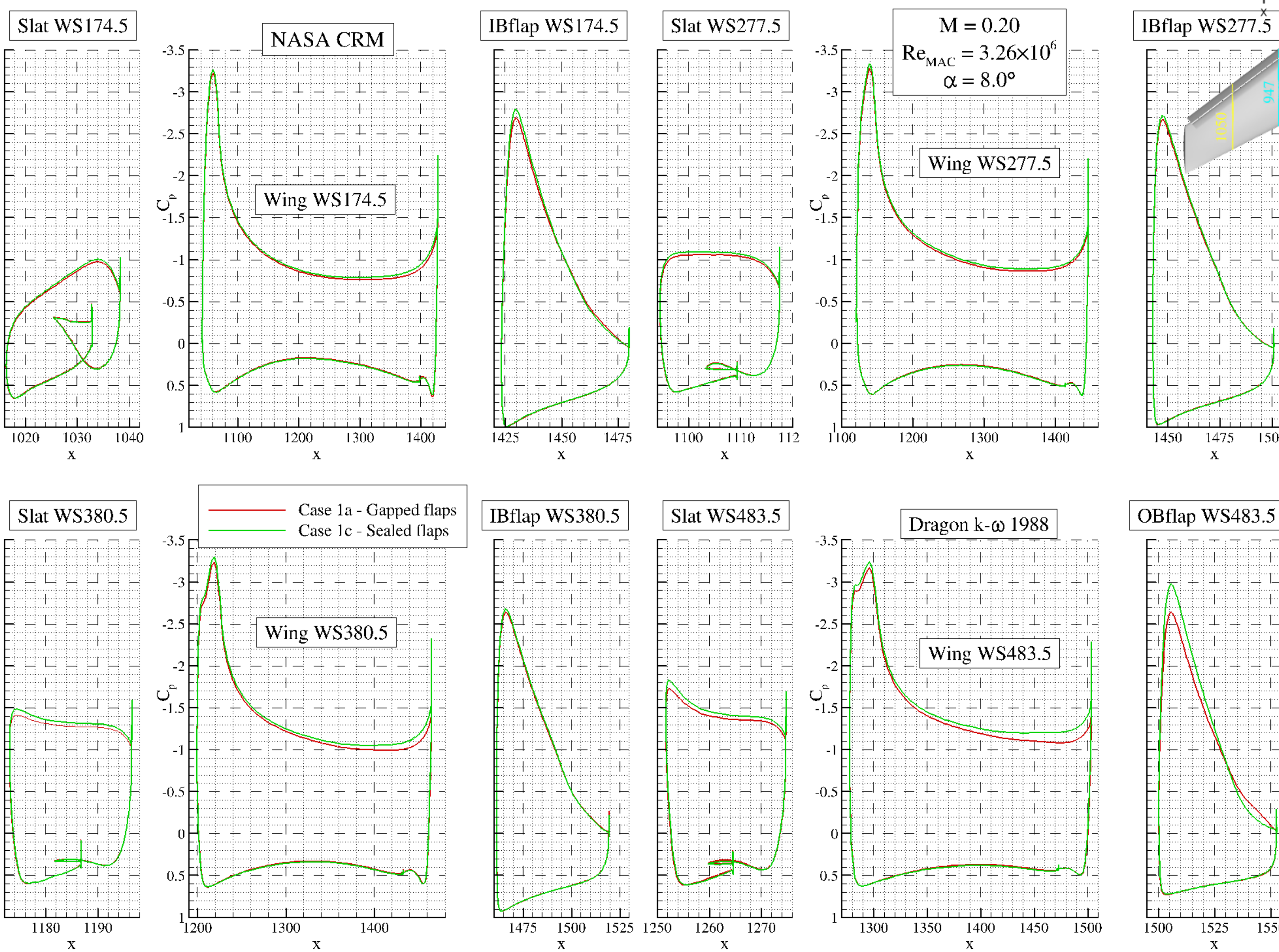
HL-CRM results – Flaps sealing: forces and moments



Sealing the flap gaps results in increased lift and reduced drag, as expected

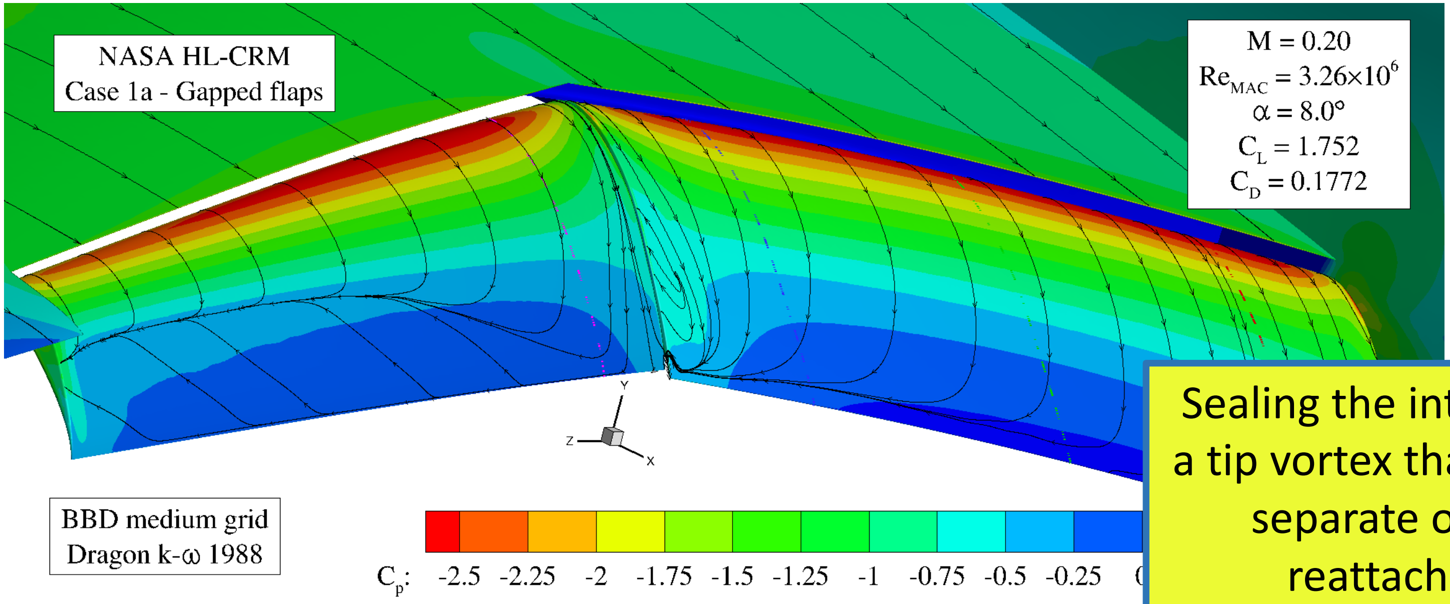
HL-CRM results – Flaps sealing: pressure distributions

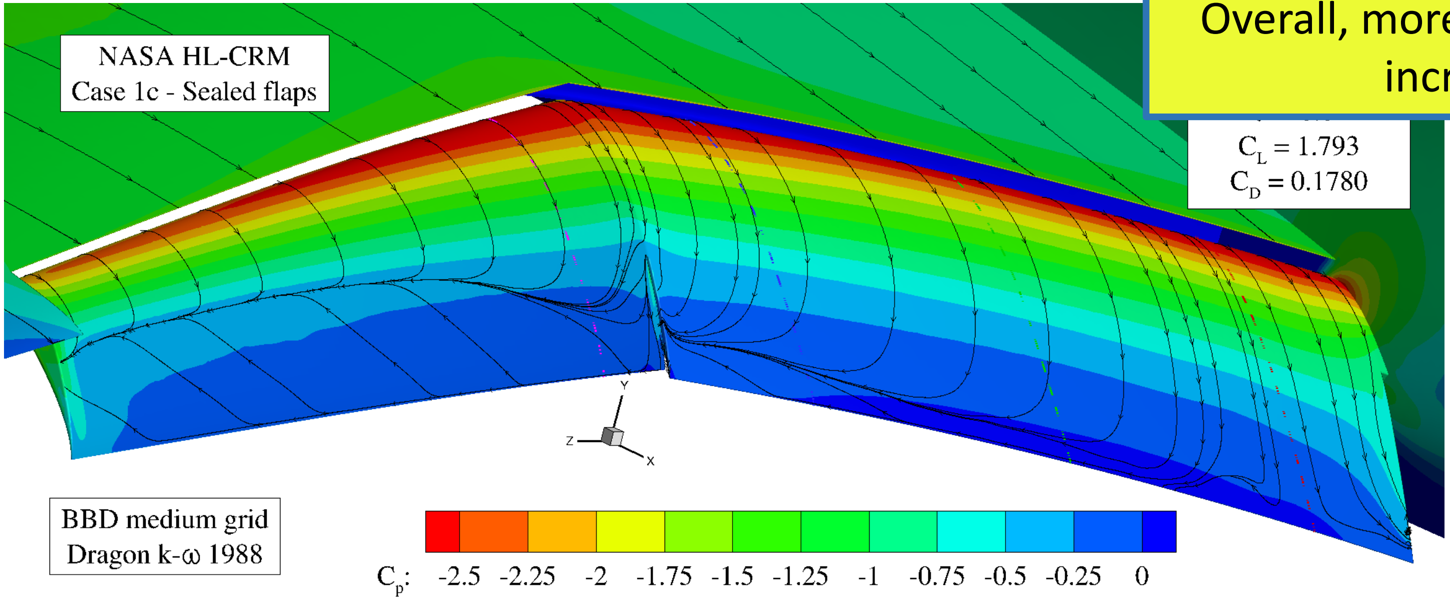




Influence of sealing is local: mid-flap C_ps are not affected

HL-CRM results – Flaps sealing: flaps flow pattern





Sealing the inter-flap gap removes a tip vortex that caused the flow to separate on the IB flap and reattach on the OB flap

Overall, more attached flow and increased C_ps

Summary

- Cases 1a/1c – NASA CRM
  - Grid convergence achieved on medium grid level
  - Bombardier coarse grid with same number of nodes/cells as B2 grid provides better flow resolution
    - ➢ Surface resolution matters
    - ➢ Important to capture tip vortices
- Cases 2a/2c – JAXA JSM
  - Fully-turbulent flow assumption not valid at this low Reynolds number
  - Good prediction of lift and stall achieved with imposed transition
    - ➢ Transition prediction essential to accurately predict high-lift flows
  - Nacelle installation effects properly predicted
  - Main flow features can be captured with a medium grid but volumic refinement/adaptation could help
  - Free-stream CFD can predict half-model WT data, but discrepencies in absolute levels of drag and pitching moment can be related to half-model effect